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A numerical model of the SEIS leveling system transfer matrix and resonances: application to SEIS rotational seismology and dynamic ground interaction.

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1. Context

The seismic sensors of the SEIS (Seismic Experiment for Interior Structure) instrument of the NASA InSight mission (Banerdt et al. 2013) are the VBBs (Very Broad Band) and SPs (Short Period). They are mounted on a mechanical levelling system (LVL) for which the purpose is twofold: provide the mechanical coupling of the instrument to the ground and ensure a level placement of the sensors on the Martian ground under yet unknown local conditions. This is possible thanks to its legs which are motorized in order to adjust their lengths. We developed a simplified analytical model of the LVL structure in order to reproduce its mechanical behaviour by predicting its resonances and transfer function. This model, based on a method to detect and compensate for inconsistent coupling conditions during seismic acquisition (Bagaini and Barajas-Olalde 2007), allows to estimate the LVL effect on the data recorded on Mars by the VBBs and SPs. Indeed, if some structure resonances are in the instrument sensitivity range of frequencies this could affect the seismic signal measurement. Moreover, the different positions of the VBBs and SPs regarding the structure's center of mass could induce off-axis effects at short period which means that a different signal will be measured between both types of sensors.

2. Numerical model

To do that, as it is shown on Fig. 1, the LVL tripod is considered as one platform and three feet, which are linked by springs in the 3 directions of space (with two horizontal k_h^p and one vertical k_v^p components).

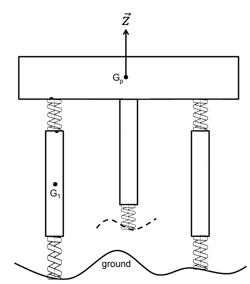

Figure 1: Schematic LVL face view in the leg 2 direction.

The links between the LVL feet and the ground are modelled in the same way (k_h^g and k_v^g parameters).

The model is implemented numerically which allows to determine the mass and rigidity matrices and resolve the eigenvalues problem to determine the LVL response [R] :

$$[R] = [P]^{-1}([K] - [M] \cdot [\Omega^2])^{-1} \cdot [P][D] \quad (1)$$

where $[P]$ is the transfer matrix toward the eigenvector base, $[\Omega]$ is the eigenpulsation matrix, and [D] represents the three vectors of ground displacement applied to the three feet in contact with the ground.

The model validation is guaranteed thanks to the observation of two horizontal resonances, between 35 and 50 Hz. These resonances are in good agreement with the laboratory measurements realized on the LVL flight model at the MPS in Gottingen, Germany. Another proof of the model fidelity to reality is the same evolution of these two resonances than with experiments according to the mass and the leg's lengths.

3. Applications

Some numerical model's parameters are adjustable but after some simulations we noticed that varying k_h^g (horizontal ground stiffness) and C_h^g (ground torque) parameters can strongly change both horizontal resonance frequencies which are in the bandwidth of SEIS measurements. This means that the LVL structure resonances depend on the mechanical coupling between it and the ground. For this reason, an inversion study is performed and compared with some experimental measurements of the LVL feet's penetration in a martian regolith analog (Delage et al. 2017) in order to see if this model could allow to estimate the ground properties at the InSight landing site.

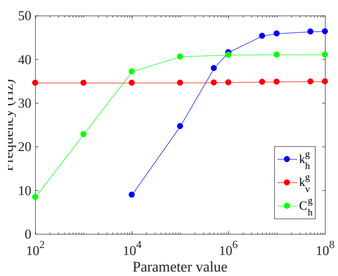

Figure 2: Sensitivity of both horizontal LVL resonances as a function of the elastic ground properties.

Another model application consists in modeling the 6 sensors on the LVL at their real positions, also considering their sensitivity axes. This study allows to compute the performances of the global 6 axes SEIS instrument in translation and rotation. Indeed, the rotation can be an important information to recover the phase velocity of the surface seismic waves (Bernauer et al. 2009). This can be realized on Mars with an active seismic experiment thanks to the other main instrument of the InSight mission: HP^3. Some simulations providing the acceleration on each LVL foot induced by HP^3 hammering (Kedar et al. 2017) are used to show the SEIS capability to estimate the phase velocity of the surface waves produced by HP^3 thanks to the combination of the 6 sensors measurements.

4. Summary

We determined the SEIS LVL's transfer function which is the last part of the seismic transfer of the signal between the Martian surface and the 6 axes accelerometer made by the 3 VBBs and 3 SPs. We have also shown that in the seismic bandwidth of the instrument, the major impact of the LVL on the seismic signal will be associated to both horizontal oscillation modes of the almost rigid LVL placed on the low rigidity ground. These resonances are highly dependent on ground properties and this can help to perform an inversion study. We finally demonstrated that the performances of the 6 axes seismometer are good enough for determining the wavefield gradient of the high-amplitude surface waves generated by the HP^3 penetration. This will allow the measurement of the phase velocity of the associated Rayleigh waves.

Acknowledgements

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