A complete characterization of 27 OSOP Raspberryshakes performed at EOST Seismic Instrumentation Facility

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Photography encouraged

Introduction:

In the scope of SeismoCitizen project (see abstract #15478), 17 Raspberry Shake 3D (3 components geophone), 5 Raspberry Shake 1D (1 vertical geophone) and 5 Raspberry Shake 4D (3 components MEMS accelerometer and 1 vertical geophone) have been fully characterized at the EOST Seismic Instrumentation Facility, before field deployment.

This facility, is usually dedicated to broad-band sensors testing. Its methods have been rethought in order to handle a complete batch of Raspberry Shakes.

In a concern of tracking and QC, we wanted to be able to efficiently calculate the transfer function and the self-noise of a complete pool in one run.

PISE - Instrumentation facility at EOST:

Its missions are to test and characterize seismic instrumentation. It can handle unitary broad-band acquisition systems as a consequent batch of instruments dedicated to dense arrays. For those purposes, some basic tasks have been automated, like acquisition, backup and retrieval data.

It hosts a dedicated concrete pier within the EOST building, and decoupled from the main room. It is a heavy structure, u-shaped as a deck (3m long, 1.5m width, and 0.6m high), relies on 2 pillar (1x1m, and 4m deep). As this structure is huge, we performed a numerical analysis and found an eigen mode frequency at ∼19 Hz, visible on almost all our analysis.

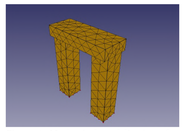

Figure 1: Mechanical modelization of u-shaped seismological pier

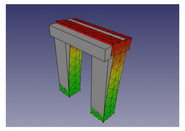

Figure 2: First eigen mode computed with CAD software

The seismometers were all tested on a dedicated concrete pier, close to a calibrated reference sensor.

Figure 3: Raspberry Shakes under characterization on u-shaped calibration pier.

Transfer function characterization:

Pavis et al. (1994) developped a calibration method to compute the transfer function of a sensor co-located with a reference sensor knowing the instrumental response of the reference. We determined the transfer functions of 27 Raspberry Shake and compared them with the theoretical ones given by the constructor.

A Python program implementing the method mentionned above was created. Data are divided in overlapping segments, then for each segment a transfer function is computed from the following formula:

$$R_2(\omega) = \frac{R_1(\omega)S_2(\omega)}{S_1(\omega)}$$

with
$S_2(\omega)$: the spectrum of the observed seismogram
$S_1(\omega)$: the spectrum of the reference seismogram
$R_1(\omega)$: the instrumental response of the reference sensor

The final transfer function is obtained by weighting all the transfer functions using a Gaussian distribution.

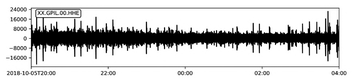

Figure 4: Recording of the east component station GPIL

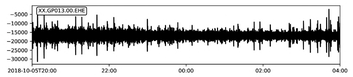

Figure 5: Recording of the east component station GP013

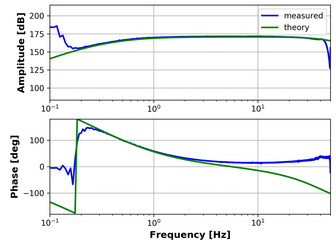

Figure 6 : Bode diagram of the instrumental response of the East component of the Raspberry Shake 3d GP013.

Self-noise estimates:

Self-noise estimate techniques are used to check the quality of a sensor, to understand the physical limits of detectable seismic signal or even to compare the self-noise level of different sensors. Generally, a coherence analysis technique using 3 co-located sensors (Sleeman et al. 2006) is performed to compute self-noise. We upgraded this technique to N sensors (N >= 3) in order to compute simultaneously the self-noise of N sensors. It gives similar results to the technique with three sensors even if the algorithm is slighly different.

Sleeman algorithm:

$$N_{ii} = P_{ii} - P_{ji}\frac{P_{ik}}{P_{jk}}$$

N sensors algorithm:

$$N_{ii} = P_{ii} - \frac{1}{2\binom{N-1}{2}} \sum_{j,k\in 1..N}^{i\neq j\neq k} \frac{P_{ji}P_{ik}}{P_{jk}}$$

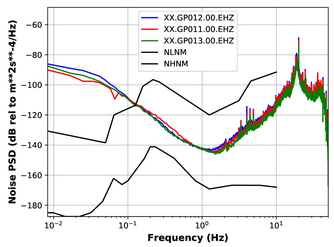

Figure 7 : Self noise estimate of 3 Raspberry Shake 3d using the algorithm with N sensors

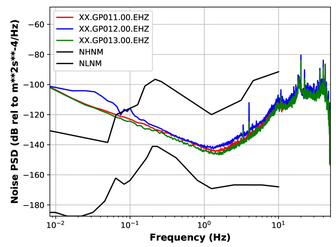

Figure 8: Self noise estimate of 3 Raspberry Shake 3d using Sleeman algorithm.

Results:

For each instrument, we computed its individual transfer function and calculated the expected error with respect to the nominal response. We found amplitudes and cutoff frequencies are constrained at better than 10% off the nominal, as announced by the manufacturer.

Model	Amplitude	Cutoff frequency
RS1Dv6	3.18 %	5.48%
RS3Dv5	2.02%	2.25%
RS4Dv6	0.38%	6.52%

Figure 9: Errors between transfer functions and theory

We observed a constant datation error of about 10 ms on RS synchronized by ntp, implying a positive phase shift at HF, dropping to 0 when RS is GPS synchronized.

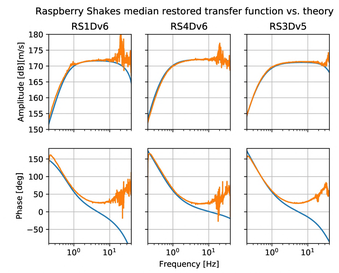

Figure 10: Restored median transfer function (orange) vs theory (blue).

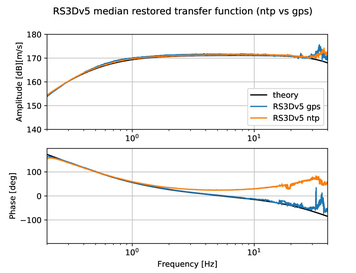

Figure 11: Restored median transfer function of RS3Dv5 synchronized by ntp or gps.

Finally, we computed the median self-noise estimate of each model of RS using the N-channel algorithm, and found significant differences at low frequencies.

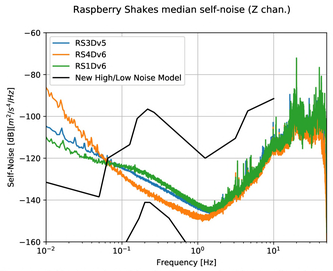

Figure 12: Self-noise estimated by the N sensors algorithm on all models

Acknowledgments:

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Bibliography:

Calibration of seismometers using ground noise, G. Pavlis and F. Vernon, 1994, BSSA, Vol. 84, No. 4, pp. 1243-1255

Three-Channel Correlation Analysis: A New Technique to Measure Instrumental Noise of Digitizers and Seismic Sensors; R. Sleeman, A. van Wettum and J. Trampert, 2006, BSSA, Vol. 96, No. 1, pp. 258–271

Technical specifications and Instructions on setting up your Raspberry Shake, available at https://manual.raspberryshake.org/specifications.html