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Installation of a monitoring system to evaluate the building response in the context of induced seismicity

Problem Description

Modelling approaches for predicting building responses to geothermal-induced earthquakes are numerous, but measurement data is scarce. Continuous monitoring was therefore implemented in the office building of a geothermal power plant over a period of ten months. The objective is to estimate the effect of induced seismicity on the building structure. Besides, artificial vibrations were generated inside the building by an impulse hammer and in front of the building by a falling weight of 600 kg to accurately characterise the building under consideration and validate the measurement results.

Building, Sensor Placement and Monitoring Concept

The chosen building has a triangular shape with 9 m by 9 m, consisting of ground, first and second floor without basement. Figure 1 shows the structure of the building. For the monitoring one geophone is installed in each floor of the building, as marked by the blue squares in figure 1. The building was in use during the monitoring period, so the locations were adapted to suit the use of the building. The Menhir system, comprising geophones with a measurement range of ± 200 mm/s and an orthogonal, triaxial topology, was utilized for the data collection [SEME23]. Continuous monitoring was conducted between June 2023 and April 2024. The results of the artificial impacts (impulse hammer and falling weight) are measured with complementary accelerometers. In Figure 1 the triaxial accelerometers are marked by blue crosses and the uniaxial accelerometers are marked by circles.

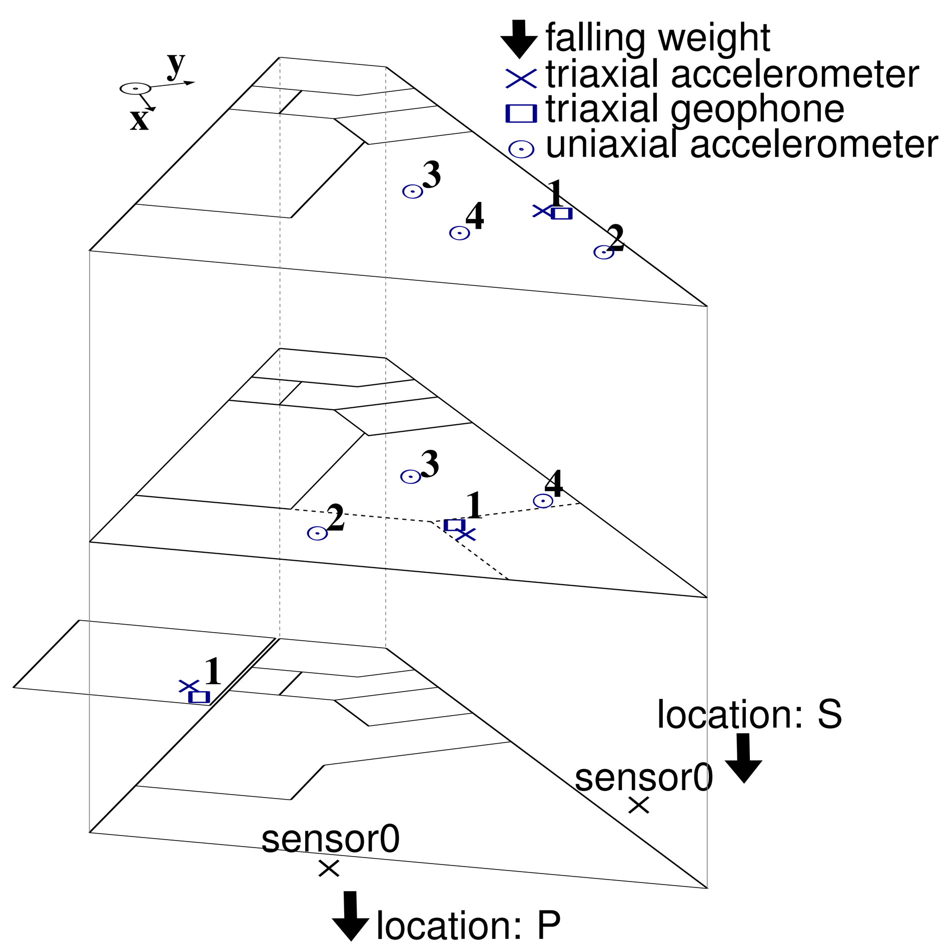

Figure 1: building structure with installed geophones, accelerometers and falling weight locations

Observations: artificial impacts

Comparison of geophone and accelerometer results: Geophones and accelerometers on ground and second floor show the same results in horizontal and vertical directions.

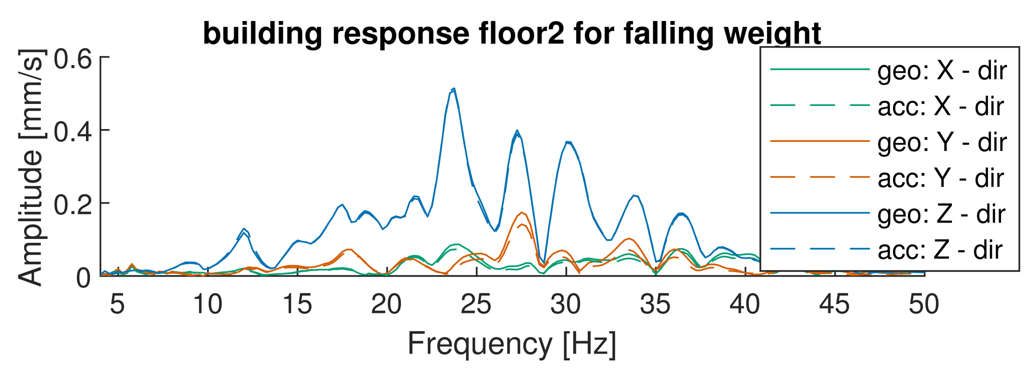

Figure 2: Amplitude spectra in second floor for falling weight excitation, results from geophone and accelerometers

Figure 2 shows an example of the superimposed spectra of geophones and accelerometers for a falling weight excitation. However, for the first floor, the geophone results differ from those of the accelerometers (note the mismatch of equally coloured lines in figure 3). Similar observations were made in the corresponding analysis of the hammer data. Thus, the following analysis focuses on the ground and second floor.

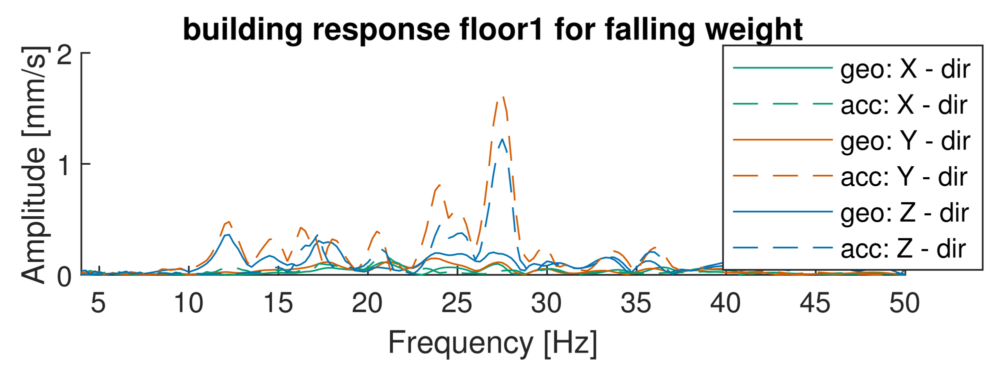

Figure 3: Amplitude spectra in first floor for falling weight excitation, results from geophone and accelerometers

Comparison of different impulse locations: The drop weight at location P produces lower peak frequencies (12.5 -16 Hz) than the drop weight at location S (31.5 Hz). In both cases, the drop weight was placed on a wooden plank. In the location S case, the plank was placed on the green area and in the location P case directly on the asphalt. These modified impact situations act as dynamic intermediate systems, influencing the spectrum of the impulse excitation.

Propagation of falling weight excitation inside the building: The upper plot in figure 4 shows the resulting vibrations at the second floor and outside the building (sensor 0). For better comparability, the data are averaged over third octave bands. The second plot in figure 4 shows the transfer functions of ground to second floor in dB. [Natk83]

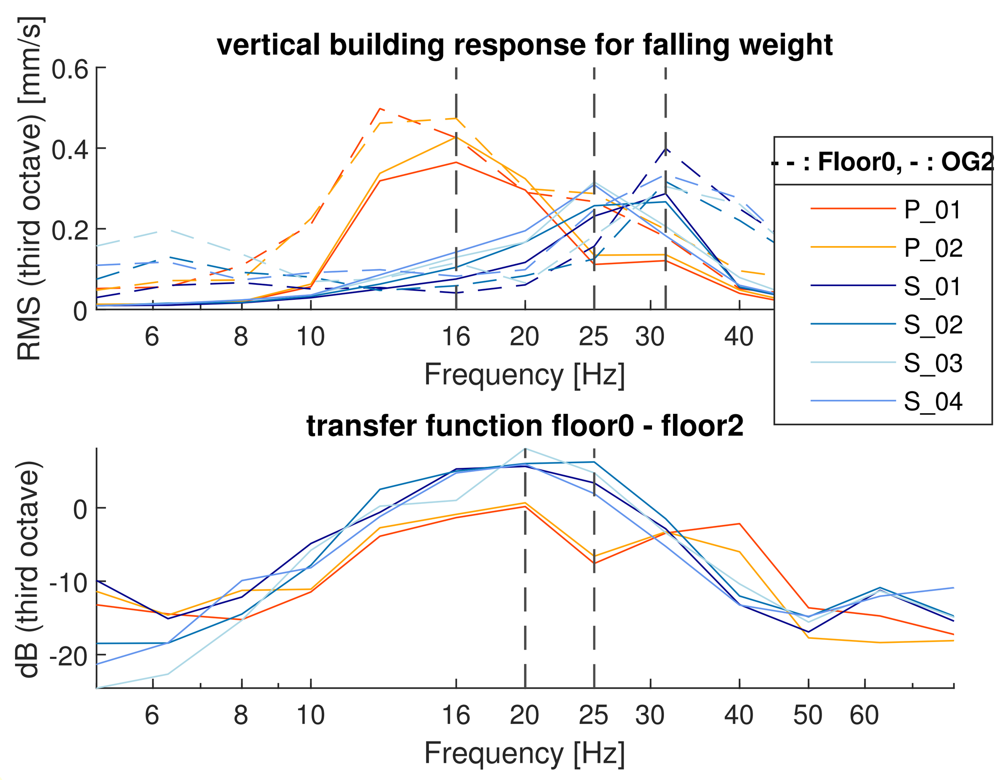

Figure 4: Vertical amplitudes for falling weight excitation: Top: third octave spectra. Bottom: transfer functions

The third octave bands of the second floor data show peaks at 16 Hz for the falling weight at location P and at 31.5 Hz for the falling weight at location S. The transfer functions, however, show peaks in the range of 16 to 20 Hz. It should also be noted that the transfer functions are predominantly negative. This means that the slab of the second floor slightly amplifies the amplitude at 16-25 Hz, but still shows lower amplitudes than the result of the outdoor sensor near the drop weight. The results in the x and y directions show a even poorer transfer of the drop weight excitation into the building. A representative transfer of horizontal vibrations into the building with the drop weight was thus not achieved.

Observations: seismic impacts

Propagation of induced seismicity inside the building: The following shows the building response to four seismic events during the monitoring period. One occurred on 20 November 2023 at 05:31 and had a magnitude of 1.4. The other three events occurred on 29 November 2023: The first at 09:32 with a magnitude of 1.3, the second at 12:38 with a magnitude of 1.8 and the third at 13:01 with a magnitude of 1.6. The seismic events occurred at a distance of about 3 km from the building. The information on the events was provided by the Bavarian Seismological Service. Figures 5 and 6 show the third octave bands at the top and the transfer functions from ground to second floor at the bottom.

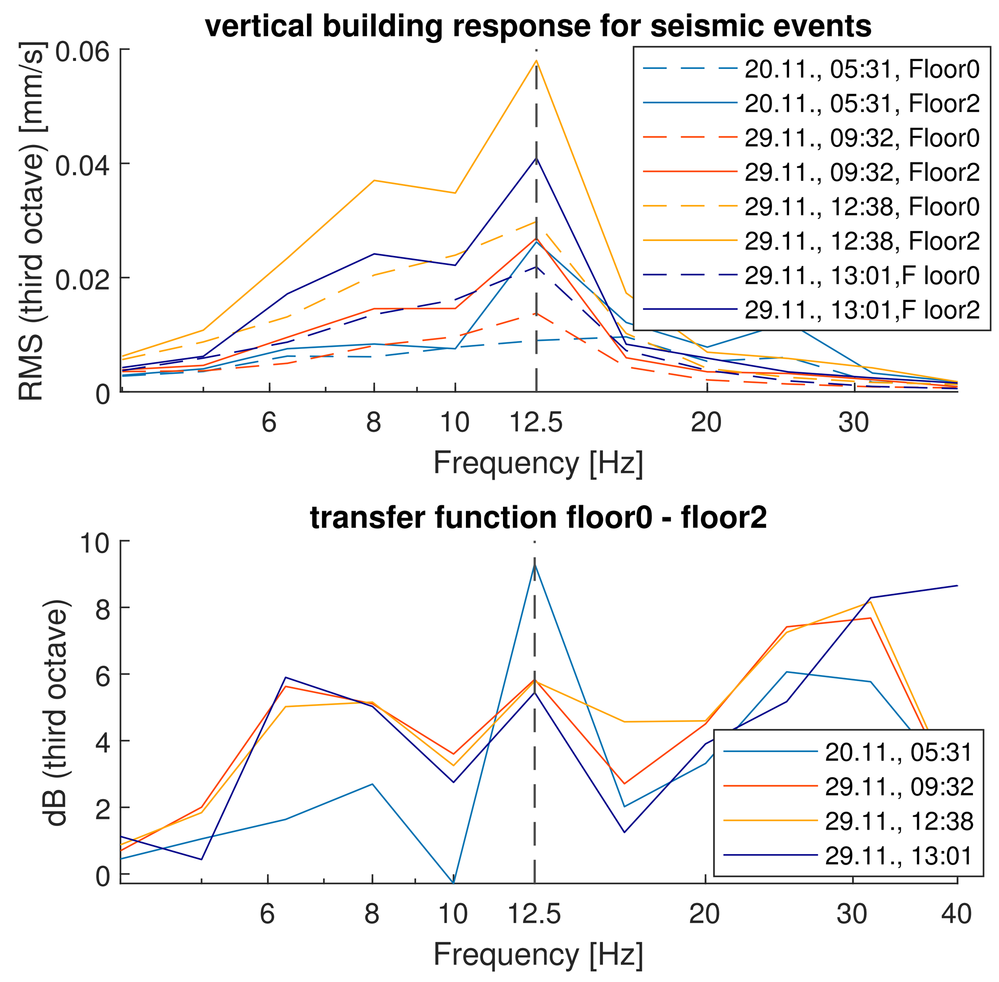

Figure 5: Vertical amplitudes for induced seismic event: Top: third octave spectra. Bottom: transfer functions

In vertical direction, the third octave bands show a clear peak of oscillations in the second floor at 12.5 Hz. The transfer function reflects this peak as a slight exaggeration compared to the ground floor. The rising transfer functions for higher frequencies are slightly exaggerated as the frequency bands get larger. In the horizontal direction, the velocities at the second floor and their transfer functions with respect to the ground floor show a significant increase at 5-6 Hz. It can also be observed that the absolute response of the slabs is higher in horizontal than in vertical direction. In both vertical and horizontal directions, the amplification from ground to the second floor is a maximum of 17 dB, reaching its maximum in the horizontal direction. The KB_{Fmax} values according to the approximation method of [DIN4150], are below 0.2, which corresponds to the limit for high comfort for storey ceilings in residential and industrial buildings. Only for the event on 29 November at 12:38, with a magnitude of 1.8, the KB_{Fmax} value reaches 0.255.

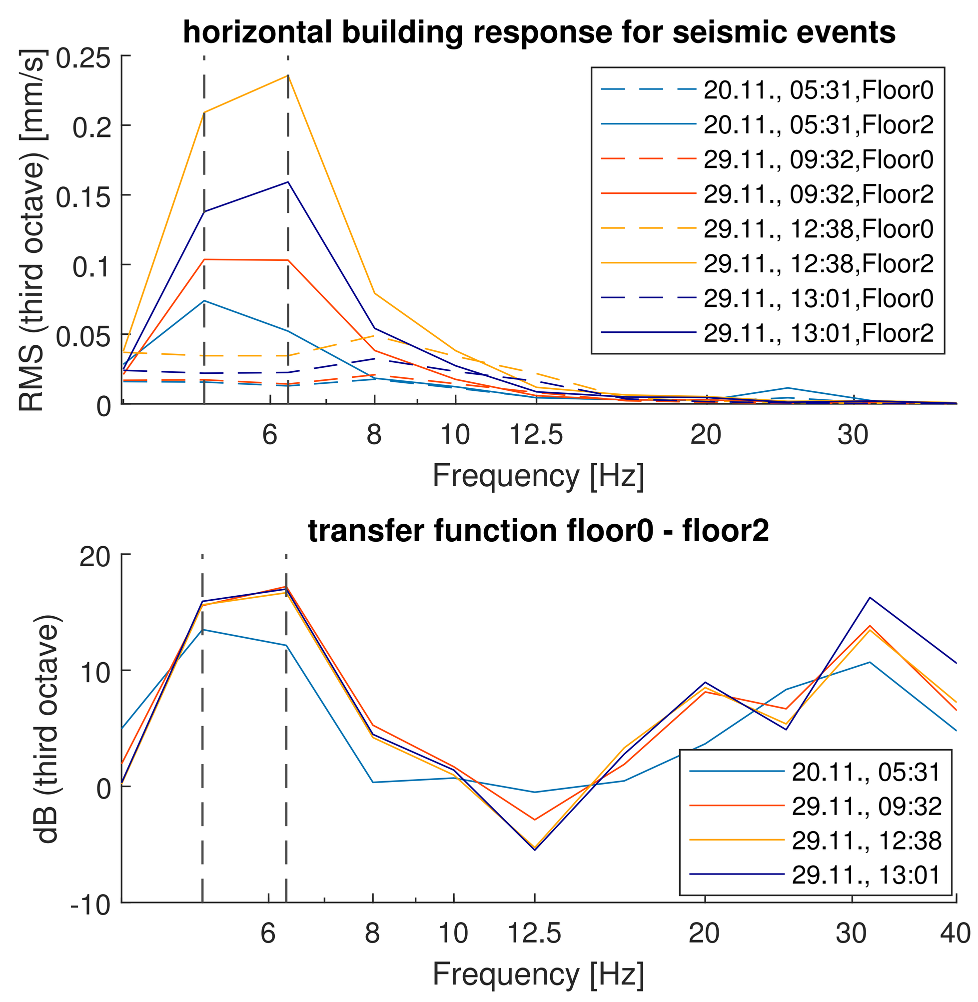

Figure 6: Horizontal amplitudes for induced seismic event: Top: third octave spectra. Bottom: transfer functions

References

[SEME23] SEMEX EngCon. Menhir – Technical Data Sheet. Version 2023-07-14.

[Natk83] H.G. Natke. Einführung in Theorie und Praxis der Zeitreihen und Modalanalyse. Springer Vieweg, 1983.

[DIN4150] DIN 4150-2: Vibration in Buildings – Part 2: Effects on Persons in Buildings. Version 1999-06.