Sources and transfer mechanism of seismic noise: Preliminary results from FEM models

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Abstract

The influence of barometric pressure changes and dynamic pressure load on seismic records is investigated with numerical models for the Geodynamic Observatory Moxa (MOX). The numerical model is based on the finite-element-method (FEM). The geometry of the model is derived from the topography in the vicinity of the observatory. It can be shown that barometric pressure, dynamic pressure and the geometry of the station vicinity have a large influence on the noise level of seismological data. The tilt produced by dynamic pressure loads caused by wind can significantly influence the quality of seismic records. The results obtained from the model are in good agreement with observed data.

1 Introduction

Interpretation of long period seismograms (and gravity records) are mainly limited by noise due to barometric pressure (BEAUDUIN et al., 1996; ZÜRN & WIDMER, 1995). Enhancements of the signal to noise ratio can be achieved i. e. by regression methods (EXSS & ZÜRN, 2002; ZÜRN & NEUMANN, 2002) or numerical models of the involved physical processes. Significant enhancements can be expected for the horizontal components of seismometers. This can be very useful in the frequency range 0.01 mHz to 10 mHz where changes in atmospheric pressure are a major source of the noise. This frequency range is also the range of the earth‘s free oscillation. Changes in barometric pressure and dynamic pressure (wind) lead to strain at the earth’s surface. This strain can cause significant tilts (strain-tilt-coupling) at the locations of seismometers or other geodynamical observation instruments (ZÜRN & NEUMANN, 2002), thus adding signals (noise) to the records. The process of strain-tilt-coupling is understood

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in principle but the real coupling in a non-uniform environment can be very complex. In additon numerical models are the only way to quantify the physical processes of strain-tilt-coupling in realistic environments.

This paper focuses on the numerical modeling of such processes at the location of the Geodynamic Observatory Moxa (MOX), Germany. The observatory is equipped (besides other instruments) with two horizontal strainmeters (north-south and east-west, each 25 m long), a laser strainmeter (forming a triangle with the two other strainmeters), a STS-1 and a STS-2 seismometer, and a superconducting gravimeter (SG CD-034). The strainmeters and seismometers are located in a 94 m long gallery. The numerical model concentrates on quantifying the tilt at the location of these instruments caused by barometric pressure and wind.

Knowledge of the physical processes and relations improves our understanding of observable phenomena related to barometric pressure in geodynamical recordings. Empirical relations between the modeled changes in pressure and calculated tilts can yield standard procedures to correct for barometric noise in the relevant frequency band.

2 The FEM-Model

The nature of the observed noise in seismological data is investigated with a numerical model of the vicinity of the Geodynamic Observatory Moxa with the finite-element-method (FEM). The model (Fig. 1) has an overall dimension of 1600 m $\times$ 1600 m in the horizontal directions and extends to a depth of 250 m below the top surface. The geometry of the model reflects the local topography around the station, which is located in a narrow valley. The entrance of the gallery is marked with a circle in figure 1. The gallery extends 60 m perpendicular to the valley axis in an east-west direction into a mountain. Then the gallery turns southwards and extends another 34 m further into the mountain. The flank of the valley rises 30 m in height with a slope of 20.8°. The gallery is included as void space in the model. The finest mesh size of the model is about 0.5 m at the gallery and the coarsest mesh size about 50 m at large distances from the observatory. The modeled elastic material has a Young's modulus of 76.53 GPa, a Poisson's ration of 0.25 and a density of 2710 kg/m^3. The boundary conditions of the FEM-model restrict the motions of element nodes at the edges of the model:

- No motion perpendicular to the edge at the northern, southern and eastern edge.
- No motion in the vertical direction at the bottom surface of the model.
- Elastic forces restrict the motion of the nodes at the western edge of the model. These forces simulate the crustal material of the western half of the valley which is not included in the model.

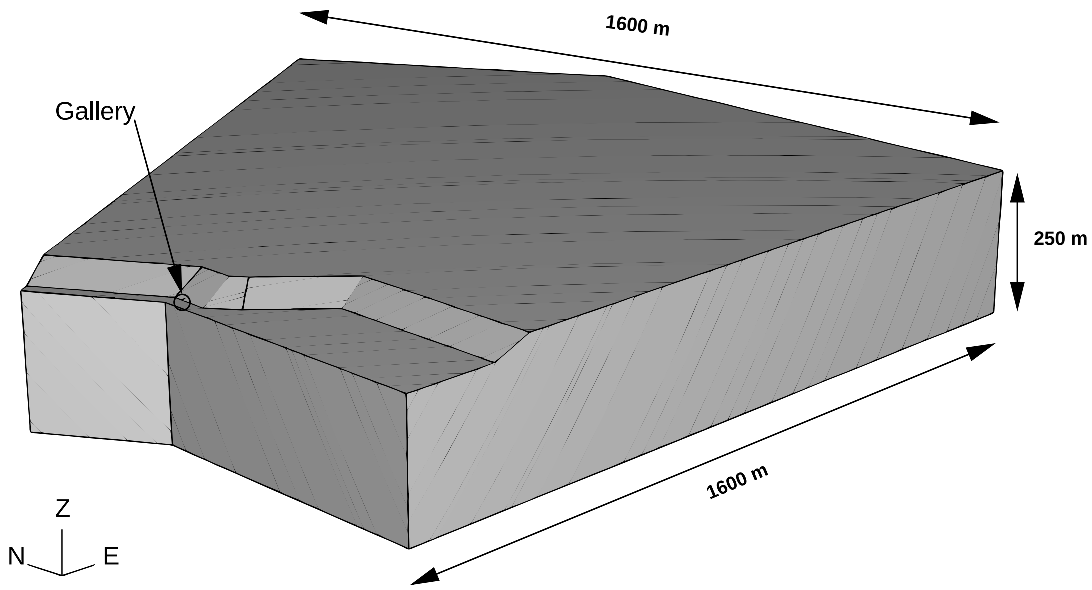

Figure 1: The FEM-model of the Geodynamic Station Moxa and its vicinity. The location of the gallery entrance is marked with a circle. Only the eastern part of the valley is included in the model.

To investigate the influence of changes in barometric pressure the model is loaded with three load cases:

1. A homogeneous pressure of 100 hPa on the top surfaces of the model.
2. A pressure of 10 hPa on the flanks of the hill simulating the dynamic pressure of the wind.
3. Case 1 and 2 simultaneously.

The obtained results for the deformation are directly proportional to the magnitude of the applied pressure. This is the result of the pure elastic rheology which satisfies the principle of superposition.

3 Results

The obtained strain and tilt at the surface of the model are shown in figures 2 and 3 respectively. It is clearly seen that the geometry of the north-south extending valley influences the direction and magnitude of the deformation significantly. The deformation decreases rapidly with depth: Strain and tilt are largest on the surface of the model and especially at the flanks of the hill and vanish in a depth of about 50 m.

More important than the deformation at the surface is the deformation at the locations of the seismometer and strainmeters within the gallery. Table 1 summarizes the strain at the location of the strainmeters and the tilt at the location of the seismometer.

3.1 Strain

The strain varies from $1.0\,10^{-9}$ to $5.7\,10^{-9}$ depending on direction and load case. The strain is about a factor of 4 higher in the north-south direction than in the east-west direction for the load case of homogeneous pressure. The dynamic pressure of the wind load leads to the same amount of strain in both components. The calculated strains are smaller than the resolution of the strainmeters. This is confirmed by the observed strain records which show no obviously correlation of the noise level with changes in barometric pressure.

3.2 Tilt

The tilt at the location of the seismometer shows a more complex pattern than the results for the strain at the strainmeter position. The highest values occur in the east-west direction in contrast to the results for the strain. These values are 2 – 3 times higher than the ones for the north-south direction. The largest difference shows up in the load-case with dynamic pressure loading only. The records of the horizontal components of the STS-1 seismometer in Moxa also show high noise level in the frequency range of 0.01 – 10 mHz on windy days (EXSS & ZÜRN, 2002). The results of EXSS & ZÜRN (2002) yield that the noise level of the north-south component correlates better with atmospheric pressure than the east-west component. This supports the modeled difference in tilt. The strong dependence of the noise level on wind speed is also seen in records of a borehole tiltmeter in front of the observatory (located in a depth of 50 m), which measures the tilt directly and not the displacement induced by the tilt. This supports the modeled difference of the load cases with and without wind.

Table 1: Calculated strain ε and tilt ϕ at the location of the strainmeter and seismometer in the gallery of the Geodynamic Observatory Moxa.

	$\varepsilon_{NS}[10^{-9}]$	$\varepsilon_{EW}[10^{-9}]$	$\phi_{NS}[10^{-9}]$	$\phi_{EW}[10^{-9}]$
barometric pressure	−4.2	−1.0	17.3	34.8
dynamic wind load	−1.5	−1.4	3.7	10.1
pressure + wind	−5.7	−2.3	21.0	44.9

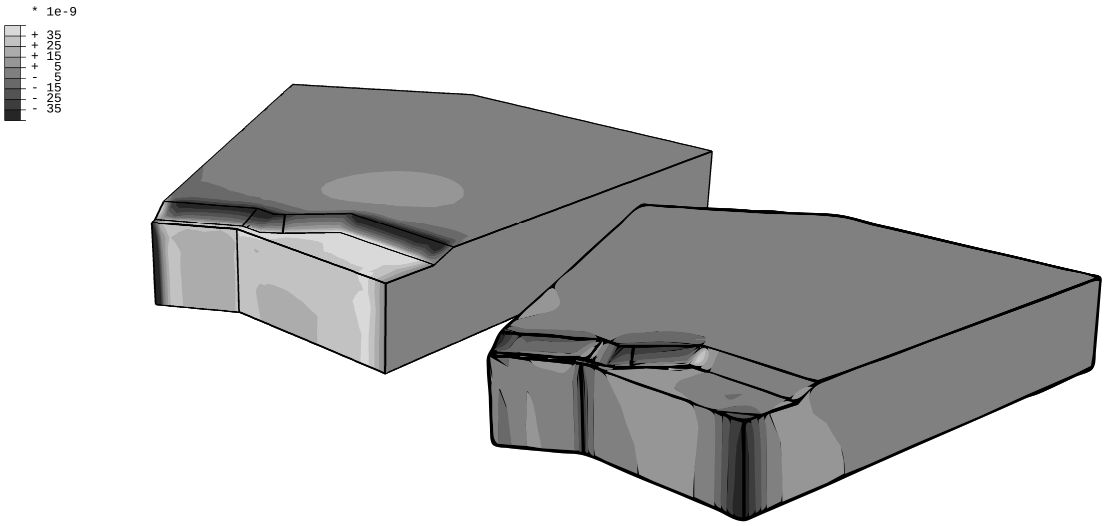

Figure 2: Strain at the model surface for the east-west (left) and north-south component (right).

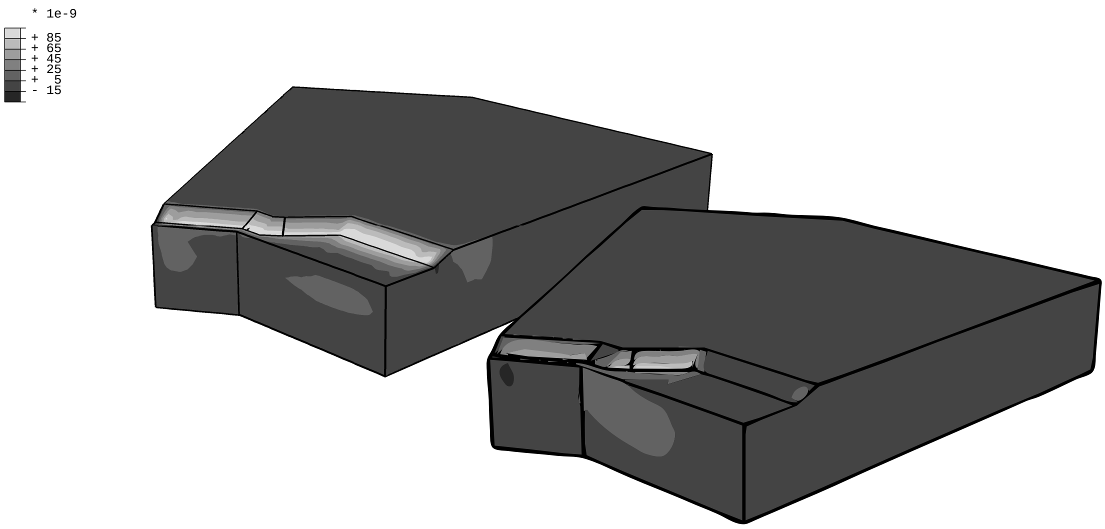

Figure 3: Tilt at the model surface for the east-west (left) and north-south component (right).

4 Conclusions

The results obtained from the preliminary numerical model are qualitatively in good agreement with the observed tilt and strain at the Geodynamic Observatory Moxa. Especially the higher values in the east-west direction of the tilt fit very good to the observed differences of the correlation of noise level and atmospheric pressure by EXSS & ZÜRN (2002). The high influence of the dynamic pressure load (wind) is clearly seen in the model and in the records of the seismometers, strainmeters, and borehole tiltmeter. The quantitative relationship between barometric and dynamic pressure and the induced tilts and strains has not been explicitly evaluated yet. This will be done for an enhanced model, which is in preparation. It can be expected that a revised model can reproduce not only the observations qualitatively but also provides a quantitative relationship between pressure and wind variations and observed noise in seismological and in other geodynamical records. The expected quantitative results will give physical explanations for the coupling between barometric and dynamic pressure and the induced deformations.

Acknowledgment

The author wants to thank C. Kroner, W. Zürn and J. Exß for helpful discussions within the common project. The financial support of the Deutsche Forschungsgemeinschaft (DFG, Germany) is greatfully acknowledged.

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