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Seismic resonance analysis for mapping a Viking Age pit house: comparison to GPR and magnetics

Dennis Wilken[a], Tina Wunderlich[a], Bente Majchczack[b], Jasmin Andersen[a] and Wolfgang Rabbel[a]

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INTRODUCTION

Seismic surface waves may show amplitude resonances at certain frequencies depending on the thickness and elastic parameters of near-surface layers. The question is whether the resonance frequencies of Rayleigh-waves can be used to prospect archaeological remains of small-scale buildings, such as pit houses.

Pit houses are small houses consisting of a man-made pit with a depth of up to 1 m and a diameter of a few metres, covered by a wooden roof. Their shape varies from rounded to rectangular. In the archaeological record, these houses are preserved as refilled hollows in the subsurface. The investigated pit house is part of a multiphase settlement on the island of Föhr (North Germany), dating mainly from the 8th to the 11th century AD. The settlement was first discovered in 2006 through crop marks found in aerial pictures (Mauritsen *et al.* 2009). The settlement has a size of approximately 10 ha and is located close to the shore on the southern edge of the Pleistocene core of the island, overlooking a salt marsh. Upon discovery, the entire settlement was prospected with magnetics (Wunderlich *et al.* 2013).

The position of the house on good accessible grassland, its small size, its clear shape observed on the magnetic map and the extensive set of collected geophysical data made it a good target for a feasibility study of the seismic method presented in this paper.

Wynn (1986) mentioned a technique called bosing (introduced by Aitken 1974). This technique is a qualitative version of the method used in this work. Bosing refers to thumping the ground with a seismic source to detect different sounds caused by resonant effects over hollows, structures, and soils of different compaction (Wynn 1986). The present paper summarizes the work of Wilken *et al.* (2015), who introduced a method based on surface-wave oscillations. The method uses an artificial seismic impulse applied at a certain point in the measurement area. The subsoil will react with its natural impulse response. The properties of this oscillation depend on the velocity-depth structure underneath the point of measurement. Oscillations on top of anthropogenic structures will thus react differently than points above undisturbed soil.

The results from resonance analysis are compared with magnetic gradiometer data and ground penetrating radar (GPR) results.

[a] Institute of Geosciences, Department of Geophysics, Christian-Albrechts-University Kiel, Germany
[a] Centre for Baltic and Scandinavian Archaeology, Schleswig, Germany

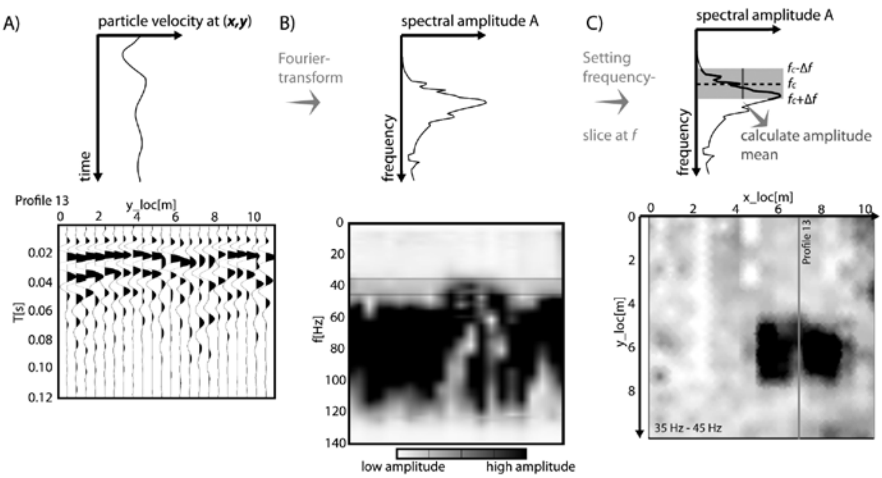

Fig. 1. Schematic view of processing steps to extract the changes in surface wave resonance frequency resulting from the pit house (A, B and C, top); sample constant offset section and amplitude spectrum of a profile crossing the pit house (A, B, bottom); sample frequency slices from 35 Hz to 45 Hz as indicated by the grey box in B, bottom (C, bottom)

METHODOLOGY

The proposed method uses an artificial seismic impulse triggered on a grid of measurement points above the pit house. The subsoil will react with its natural impulse response oscillation, which is recorded with a geophone mounted on a steel plate at 1 m distance to the source point. The spectral properties (resonance/peak frequencies and amplitudes) of the oscillation depend on the velocity-depth structure underneath the point of measurement. In order to analyze and visualize changes in resonance behavior, "frequency slices" were calculated, representing the recorded spectral energy in a narrow frequency band as a function of geophone coordinates (x, y).

RESULTS

The results of the frequency slice analysis of the Rayleigh-wave resonance dataset are shown together with schematic diagrams of the processing (Fig. 1). One sample profile was chosen to highlight the occurring effects. The profile crosses the centre of the pit house. Looking at the 1 m constant offset section (Fig. 1: A), the profile shows fairly coherent phases outside the pit, whereas a slight traveltime delay and, looking at the signal length, a shift to lower frequencies can be observed inside the pit. The latter effect can easily be observed in the amplitude spectra of the profile (Fig. 1: B). To map this effect on the measurement area, a frequency slice from 35 Hz to 45 Hz, where the effect is observed, was plotted (Fig. 1: C). A clear rectangular shape is visible here; it corresponds to the higher amplitudes in lower frequencies due to the described frequency drop. The high amplitude area correlates well with the position of the pit house.

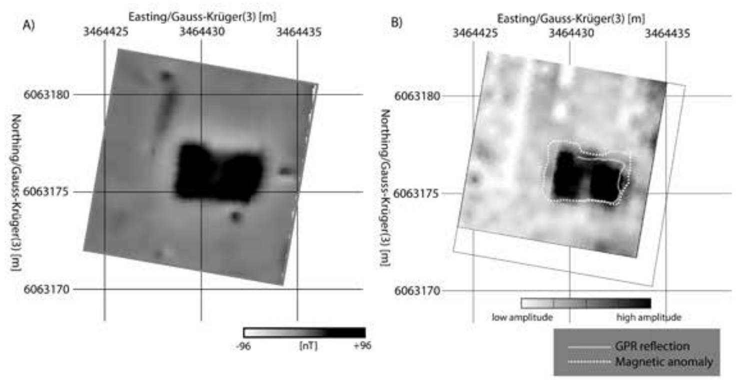

Fig. 2. Magnetic result (A) and 35 Hz to 45 Hz frequency slice from the seismic experiment, together with perimeters of the pit house signal from magnetics and GPR (B)

A final comparison was made between magnetic data showing the signal of the pit house (Fig. 2A) and the GPR data with reflection signals of two different depths (black and grey lines) and Rayleigh-wave resonance mapping data (Fig. 2B), which also shows the frequency slice derived from the seismic data. The perimeter of the house has been marked with a dashed, black line. The comparison evinces the good correlation between magnetic and seismic results. The magnetics also show that the pit house signal is somehow split into two parts, a characteristic also reflected by the seismic result. In terms of the GPR, only the reflection that corresponds to the bottom of the pit correlates well with magnetics and seismics. This effect is due to the non-horizontal shape of the reflection of the top of the pit. The seismic result furthermore shows the highest amplitudes, where the deepest part of the pit is situated (derived from GPR) and where the largest magnetic anomaly was observed.

CONCLUSION

The test showed that the pit house can be mapped by Rayleigh-wave resonance analysis with an adequate lateral resolution. The progress of seismic field measurement is slow compared to GPR and magnetic methods.

The method in the present application is a promising add-on to conventional prospection methods and can be used on specific targets as a support method with access to elastic subsoil parameters or as an alternative approach in areas were electromagnetic or magnetic methods show no contrast or only weak contrast.

A second example from a comparative study to image a Viking Age turf house in Iceland is presented in Wunderlich *et al.* (2015).

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