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A seismological study of shallow weak earthquakes in the urban area of Hamburg city, Germany, and its possible relation to salt dissolution

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In the night from 8/9 April 2009, shortly after midnight on Maundy Thursday before Easter, several people in Gross-Flottbek, Hamburg, felt unusual strong ground shocks so that some of them left their houses in fear of earthquake shaking. Police and Fire Brigade received phone calls of worried residents, and few days later Internet pages were published where people reported their observations. On 21 April 2009 at about 8 p.m. local time a second micro-earthquake was felt. Damage to buildings or infrastructure did not occur to our knowledge. The Institute of Geophysics, University of Hamburg, installed from 22 April to 17 May 2009 three temporal seismic stations in the epicentral area. Seismological data from two close-by stations at the Deutsches Elektron-Synchrotron (DESY) in about 1 km and the Geophysical Institute in about 7 km distance were collected and integrated to the temporal network.
The events occurred above the roof of the shallow Othmarschen Langenfelde salt diapir (OLD), in an area known for active sinkhole formation and previous historic ground shaking events. The analysis of the seismological data recovers that three shallow micro-earthquakes occurred from 8 to 21 April at a depth of about $100\,m$, the largest one with a moment magnitude of about M_W 0.6. Depth location of such shallow events is difficult with standard methods, and is here constrained by waveform modeling of surface waves. Earthquakes occurring in soft sediments within the uppermost 100 m are a rare phenomena and cannot be explained by standard models. Rupture process in soft sediments differ from those on faults in more competent rock. We discuss the rupture and source mechanism of the earthquakes in the context of previous historic shocks and existing sinkhole and deformation data. Although the event was so weak, the rupture duration was unusual long and possibly 0.3 s. Three possible models for the generation of repeated micro-earthquakes in Gross Flottbek are developed and discussed, implying quit different hazards for subsidence, ground motion and sinkhole formation. Our favored model postulates that roof failure occurs in an existing soil cavity beneath the epicenter at a depth of about 100 m. Other models bearing a smaller geo-hazard cannot be disproved with the data available, but future geophysical experiments may be planned to resolve this question.