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Detection of sinkhole formation via Brillouin Optical-Fiber Time-Domain Reflectrometry (BOTDR)

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Sinkholes have been considered a major natural hazard in the Dead Sea region since their apparition more than 15 year ago. Although these sinkholes develop slowly over several months, they collapse very suddenly without any warning signs, which makes them especially dangerous to both people and infrastructures.

The most commonly accepted mechanism for sinkholes formation in the Dead Sea area is dissolving of salt in subsurface layers. As a result of salt dissolution, the load that was carried originally by the salt layers is transferred to the other soil layers. When this load exceeds the layers' holding capacity, collapse occurs. Throughout this load-transfer process, small mechanical deformations must develop in the soil and the present study investigates the use of Brillouin Optical-Fiber Time-Domain Reflectrometry (BOTDR) for detecting these changes. BOTDR uses the Brillouin-scattering of the light along the optic fiber to estimate the temperature or strain profile in the fiber in a distributed manner. Following temperature compensation, such a system allows for nearly-continuous distributed monitoring of strains over distances of tens of kilometers with a spatial resolution of about 1 meter.

In the present study, an analytical solution of the strains that develop in the soil due to sinkhole development was used to simulate the BOTDR signals that would be produced by an optic fiber buried one meter below the soil surface. These simulated "ideal" signals were corrupted artificially to account for the actual spatial resolution of the signal analyzer and random measurement errors. In addition, BOTDR signals due to above-surface disturbances (400kg loading and rain) that were obtained experimentally, were superimposed to the simulated signals. Three thousands BOTDR signals were generated with sinkhole radii and depths ranging from 1.5 to 4.0m and from 10 to 30m, respectively. These signals were subjected to wavelet decomposition and the most informative wavelet coefficients were used as inputs for a neural network that was trained to recognize the "wavelet signature" of a sinkhole.

The results show that the neural network can indeed differentiate between sinkholes and disturbances (false alarms rate below 10%) and that large sinkholes (radius>3m) are always detected (up to the depth investigated). For sinkholes with radius ranging from 2.5 to 3m, the detection rate is above 85% if the sinkhole depth is less than 25m. Beyond this depth the detection performance drops sharply (to about 60%). For shallow sinkholes (depth<15m), all the sinkholes with a radius larger than 2m are detected. These results are very encouraging and demonstrate the high potential of this method for fully-automated early-warning detection of sinkhole formation in the Dead Sea region. Work is currently under way to develop a finite difference model of the sinkhole formation process. Preliminary results indicate that the strains predicted by the simple analytical model used so far are conservative so that the actual detection rate should indeed be higher.