Optical-fiber stress sensors predict landslides

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Optical-fiber sensors embedded into suspect hillsides track subsurface differential forces, enabling accurate, early warning of major rock and soil events.

Landslides are among the most costly natural disasters in terms of human lives and infrastructure damage. Predicting them with sufficient time to avert catastrophe is an urgent goal. In nature, landslides take place when the weight of a hill’s soil exceeds the countering frictional forces that hold it in place. Many landslide-monitoring approaches have been investigated in the past several years—such as electromechanical displacement measuring, topographic surveys, and GPS surveys—with mixed results. Landslide prediction is complicated because ‘soil’ is not a uniform substance: it includes randomly distributed rocks and roots, clays and compost. Moreover, landslides are a highly localized phenomenon. In witnessing the aftermath of a landslide, as remarkable as the amount of soil that fell is the amount of soil that remained in place. Improving forecasting requires monitoring the internal mechanical-property distribution and variations of the soil composite, or ‘landslide body.’ We have developed fiber-optic stress sensors that can be embedded inside the landslide body, enabling remote, real-time measurement of differential stresses such as shear and compression. These measurements can then be combined with specific geological models for more accurate results.

Figure 1 shows the monitoring configuration. Our sensor comprises optical fibers inside steel tubes. In application, vertical holes are drilled in the landslide body down to bedrock, and the sensors are laid down in the holes. The soil around the sensors is backfilled so that differential stresses between the bedrock and the landslide body, and within the landslide body itself, are accurately felt by the sensors.3, 4

The sensing system has been implemented in a field trial at the Three Gorges mountain area in China and at other locations. Figure 2 shows one such emplacement. Figure 3 shows the curve of pressure over time in four directions in one of the field-trial boreholes at a depth of 10m. Automatic measurements were made every other day over a period of one month. We established a profile of the internal mechanical properties and variations along each borehole. We also built up a stress-time database for the entire site.

We have developed two kinds of distributed-stress sensing systems: optical time-domain reflectometry (OTDR) and optical frequency-domain reflectometry (OFDR).4–6 Both rely on backscatter light measurement. The OTDR system uses pulsed laser sources and direct detection. This technology poses a trade-off between dynamic range and spatial resolution. The typical spatial resolution is about 1m, dynamic range about 40dB, and sensitivity limited to about –50dBm. OFDR offers higher resolution than OTDR due to its inherently coherent detection, higher sensitivity, and larger dynamic range. In fact, we have achieved spatial resolution of 5cm, dynamic range of about 70dB, and sensitivity less than –80dBm. OFDR is, however, considerably more expensive than OTDR. Because OTDR is a mature technology, Continued on next page
The OFDR-based system also includes polarization-mode coupling.\textsuperscript{5} When stresses are applied on a polarization-maintaining fiber (such as we use), part of the light is coupled from one polarization mode to the other at the stress points. Coupling losses are proportional to the intensity of external stress where it occurs. Consequently, combining the polarization-mode coupling method with the OFDR technique\textsuperscript{7} makes it possible to measure the intensity and location of the external stress with high accuracy and high spatial resolution. Figure 4 shows the results of a test of the OFDR sensor’s spatial resolution. The graph indicates a clear response from the application of two 200g pressure devices spaced 5cm apart and arranged to exert shear stresses along the PMF. We are currently installing sensing systems of this type in certain landslide-prone areas in China to collect more data to enable earlier, more accurate prediction of landslides.

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