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Dynamic Strain Measurements Using Embedded Fiber Optic Sensors

Geodetic monitoring of structures like bridges or dams, and natural objects like slopes, and the determination of deformations has reached a high level of maturity considering the instrumental as well as the analysis developments. But classical geodetic instruments rarely provide high data rates. For example, geodetic deformation surveys with total stations are usually carried out at certain repeated period of times, e.g. annually for dams or with periods of some hours or even minutes for individual monitoring projects. During the past 20 years GPS measurements have been used to continuously measure deformations with very high precision of several millimetres. But on a global scale – global refers here to the structure and its surroundings – the geodetic data are extremely important as they are the sole source of information about the integral behaviour of a structure. The use of embedded sensors can overcome the barrier of the structure's surface for geodetic measurements. Embedding sensors is of course possible during the construction of a new building, otherwise the sensors have to be applied to the structure's surface. For this purpose fiber optic sensors (FOS) have emerged as the most useful sensor type. FOS have also unique properties, e.g. electromagnetic immunity, long term stability, small dimensions or multiplexing availabilities. The optical fibers can be used as sensors as well as for the transmission of the signals which allows the analysis unit to be quite distant to the measurement site. Recently a study of a fiber optical tiltmeter was completed, and a novel calibration facility of FOS has been developed. However, in this contribution two applications of FOS will be presented where dynamical measurements of strain values are essential. In the first application, long gauge fiber optic sensors (5 m length) were used for the measurement of a large geotechnical structure, in the second Fiber-Bragg-Grating sensors (5 mm length) were used to determine the deformations inside of a rather small structural element.

Large Strain-Rosette on alpine slopes, deep-seated gravitational creep is a frequently observed phenomenon. However, the causes and mechanisms of these landslides are understood insufficiently for the prediction of motions. The GPS monitoring results show that the motion of the mass movement is not uniform but rather intermittent, i.e., periods of accelerated motions (velocities up to 2 m/year) are followed by quiescent periods. However, GPS surveys are not sufficiently precise and fast enough to allow for a detailed study of this pattern of motions. But very precise dynamic measurements of the local strain situation could yield an insight into the geomechanics of this behaviour of a landslide which is required for the prediction of the landslide's motions. Therefore, we have developed an embedded strain rosette for dynamic in-situ measurements of local distance changes. The strain rosette consists of three 5 m long extensometers at a separation of 120° in orientation. The extensometers are long gauge fiber optical sensors of the SOFO type. Each sensor was embedded in a separate trench at a depth of about 2 m, where it was attached to two concrete anchors of 0.5 m length and 0.3 m diameter. The main challenge of embedding the sensors was their proper connection with the rock material. At the landslide area, mass movements cause micro-earthquakes, which occur approximately once a week and have duration of less than 0.1 s. The exact relationship between these micro-earthquakes and the mass movement is unknown. It is one of the purposes of the strain rosette to detect possible strain waves associated with the Gradenbach deep-seated mass movement. In order to investigate the capability of the strain rosette to measure strain waves, artificial excitations were used. The strain variations were generated by hammer (5 kg) impacts to the ground and data were acquired with the SOFO Dynamic reading unit with a sampling frequency of 1 kHz. First experiments have shown very small signal amplitudes, e.g. 0.14 µm for hammer impacts 5 m away from the strain rosette's centre Z. With increasing distance, they even get smaller due to energy dissipation and absorption in the soil and they quickly get down to the noise level of the measuring system. Thus, at each point, 16 consecutive hammer impacts were performed and the signals were time-stacked. The experiment comprised hammer impacts at various distances and orientations from Z. The noise level of the system is sdL = 0.4 nm and at this distance the amplitudes of the signal are as small as about 1 nm. This highlights the very high resolution of the measured strain variations using the SOFO Dynamic reading unit and the strain rosette. Other experiments have confirmed the high reproducibility of the signals which is in the nanometre range. Using this highly sensitive measuring system, we now hope to find the signals of the rare microearthquakes.

In conclusion, it should be noted that these two examples show the implantation of FOS in existing structures of different size, and embedding of the FOS when the structure is being built up. Both examples have shown the potential of the fiber optic instruments used, especially for dynamic measurements. SHM is a growing discipline with many new applications and thus new FO instruments with enhanced performance or even new functionality will be available in the future.