A SENSOR FOR MEASURING STRESS AND STRAIN IN ROCKS AND CONCRETE

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A geomechanics measurements task is considered: determining stress and strain in rocks and concrete by the use of photoelastic sensors. A sensor is described for measuring stress and strain.

Photoelastic sensors are used [1-9] in research on the states of stress and strain in rocks in geomechanics, in concrete dams in hydroengineering, in rock and concrete supports to bridges, and in foundations in building. A simple sensor for the purpose is a cylinder having a small axial hole and made of an optically sensitive material (usually silicate glass). One end is coated with a reflecting layer, and data can be obtained from it by means of a polarized light beam. This optical device is mounted in the wall of the borehole and is strained along with the surroundings when there are any changes in the state of stress or strain. Mechanical stresses arise in the sensor in proportion to the changes in the stresses or strains. When the sensor is illuminated by a beam of polarized light, an optical pattern arises from which one can judge the increments in stress or strain.

The Mining Institute, Siberian Division, RAS, has established that the readings of a high-modulus borehole photoelastic sensor are proportional to the stresses in the rock (concrete) if

\[ \frac{E_1}{E} \geq 4, \]  

(1)

where \( E_1 \) and \( E \) are the elastic moduli of the sensor material and the rock respectively.

If

\[ \frac{E_1}{E} < 1, \]  

(2)

the readings are proportional to the increment in the strain in the rock.

Here we consider a photoelastic sensor for the simultaneous measurement of stresses and strains in rock and concrete. The device consists of two series-connected coaxial cylinders made of optically sensitive materials (Fig. 1).

Cylinder 3 is made of high-modulus K8 optical glass, while the second cylindrical element 2 is made of low-modulus SD polystyrene. The bottom end surface of each of the cylinders is coated with a mirror layer. The upper low-modulus cylinder has an axial hole whose diameter is greater than that in the lower one. The axial hole in the upper cylinder can therefore be used to observe part of the optical pattern around the axial hole in the lower one. The high-modulus cylinder is the stress sensor, while the low-modulus one is the strain one.

Figure 2 shows the optical scheme for observing the sensor. The two beams \( a' \) and \( b' \) from the light source 6 pass through the polarizer in the polariscope (polaroid 5 and quarter-wave plate 4) and enter the sensor. Ray \( a' \) falls on the low-modulus component 10 and is reflected from the mirror layer 11, returning as ray \( a'' \) to the polariscope, where it passes through the analyzer (quarter-wave plate 9 and polaroid 8) to the observer's eye 7. That ray provides information on the increment in the rock strain. A second ray \( b' \) passes to the second cylinder 12 and through it to the mirror layer 13, from which it returns as ray \( b'' \) to the polariscope and then to the observer's eye. Ray \( b'' \) gives data on the increment in the stresses in the rock occurring after the sensor is installed.

The sensor is attached to the wall of the borehole by means of a spontaneously hardening cement [1, 3], which is usually a material based on epoxide resin or a cement solution. In Fig. 2, this layer of cement is denoted by 2. Component 1 is a
Fig. 1. Essential scheme for an FDO-2E sensor: 1) metal ring protecting the front surface; 2) annular cylinder made of SD optically sensitive polystyrene; 3) annular cylinder made of K8 optical glass; 4) plastic disk protecting the mirror layer; 5 and 6) mirror layers.

Fig. 2. Optical system for observing photoelastic sensor: 1) wood plug at end of borehole; 2) glue layer; 3) borehole; 4) quarter-wave plate; 5) polarizer; 6) light source (may be part of polariscope); 7) observer’s eye; 8) polarizing plate; 9) quarter-wave plate; 10) low-modulus polystyrene component; 11) mirror layer in low-modulus component; 12) high-modulus glass component; 13) mirror layer on high-modulus component. Components 4, 5, 8, and 9 are parts of the polariscope; a' and b' are rays entering the sensor; and a'' and b'' are rays emerging from it.

wooden plug at the end of the borehole, which eliminates any effect from the end of the borehole on the operation of the sensor, i.e., it ensures that a sensor works under two-dimensional conditions.

The theory shows [1, 4, 6, 10] that such a sensor reacts to the quasiprincipal components of the stress or strain in the rock in the plane normal to the axis of the sensor and borehole. Figure 3 shows the scheme for an annular sensor, in which \( p \) and \( q \) are the increments in the quasiprincipal stresses in the rock, \( R \) the outside radius of the annular element and \( R_1 \) the inside radius. It is usually assumed that the rock and the sensor material are elastic, homogeneous, and isotropic ones. The corresponding problem in the theory of elasticity concerns a plane weakened by a circular hole but reinforced by an elastic ring and uniformly loaded by distributed forces \( p \) and \( q \) is handled subject to the following boundary conditions and linkage ones on the assumption of complete adhesion at the contact between the sensor and the borehole wall:

1) boundary conditions at the inner edge (\( r = R_1 \))

\[
\sigma_{r1} = 0, \quad \tau_{\phi1} = 0;
\]