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Hydraulic fracturing stress measurement in underground salt rock mines at Upper Kama Deposit

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Abstract. The paper reports the experimental results on hydraulic fracturing in-situ stress measurements in potash mines of Uralkali. The selected HF procedure, as well as locations and designs of measuring points are substantiated. From the evidence of 78 HF stress measurement tests at eight measuring points, it has been found that the in-situ stress field is nonequicomponent, with the vertical stresses having value close to the estimates obtained with respect to the overlying rock weight while the horizontal stresses exceed the gravity stresses by 2–3 times.

Accident-free operation of Upper Kama potassium mine is impossible without prompt information support on stress–strain state of the salt rock mass. One of a few techniques applicable to the experimental determination of in site stresses deep in the salt rock mass is hydraulic fracturing. Capacities of the other known approaches are limited due to the structural features and nonlinearity of deformation of such geomedia under loading.

In 2015–2016 in underground mines of Uralkali, an experimentation series on determination of actual stress field parameters was undertaken using measurement-and-computation equipment Gidrorazryv (hydraulic fracturing in Russian, engineering design by the Institute of Mining, SB RAS) [1]. The first stage experiments showed that it was necessary to design a special drilling tool capable to ensure drilling at high geometric accuracy to satisfy hydrofracturing standards such as absence of deviation of drilling or misalignment of hole with jog formation, inadmissibility of jamming or ejection and solidification of clayey bands in holes, etc. to this effect, for the purpose of hydraulic fracturing stress measurement, the drilling tool, drilling assembly, splitter and hole gauge have been designed [2].

An important point of the hydraulic fracturing stress measurement is selection of locations and designs of measurement stations. When selecting the locations, the distance between the test site and the mining front was taken into account, and it was also required that the measurement area was not undermined or overmined and was suitable for placement of drilling equipment. Figure 1 shows the locations of the measurement stations in mines SKRU-1, SKRU-2 and SKRU-3 of Uralkali.

The measurement station design (number of holes and their directions) was first of all connected with the calculation procedure of the actual stresses by the data of hydraulic fracturing tests in a number of wells. Traditionally the hydraulic fracturing stress measurement presupposes testing in three wells: one vertical and two horizontal. Horizontal drilling in accordance with the the hydraulic fracturing stress measurement standards is more laborious that vertical. In Mines SKRU-1 and SKRU-2, horizontal drilling appeared impossible due to the work situation as compressed air was inavailable for cleaning wells from drill cuttings. In this connection, the procedure offered in [3] was used; it allows determining values of vectors of principal stresses in rocks mass in the plane of drilling by the test data obtained in three arbitrarily directed wells so long as the hydrofracture is orthogonal to the well axis.

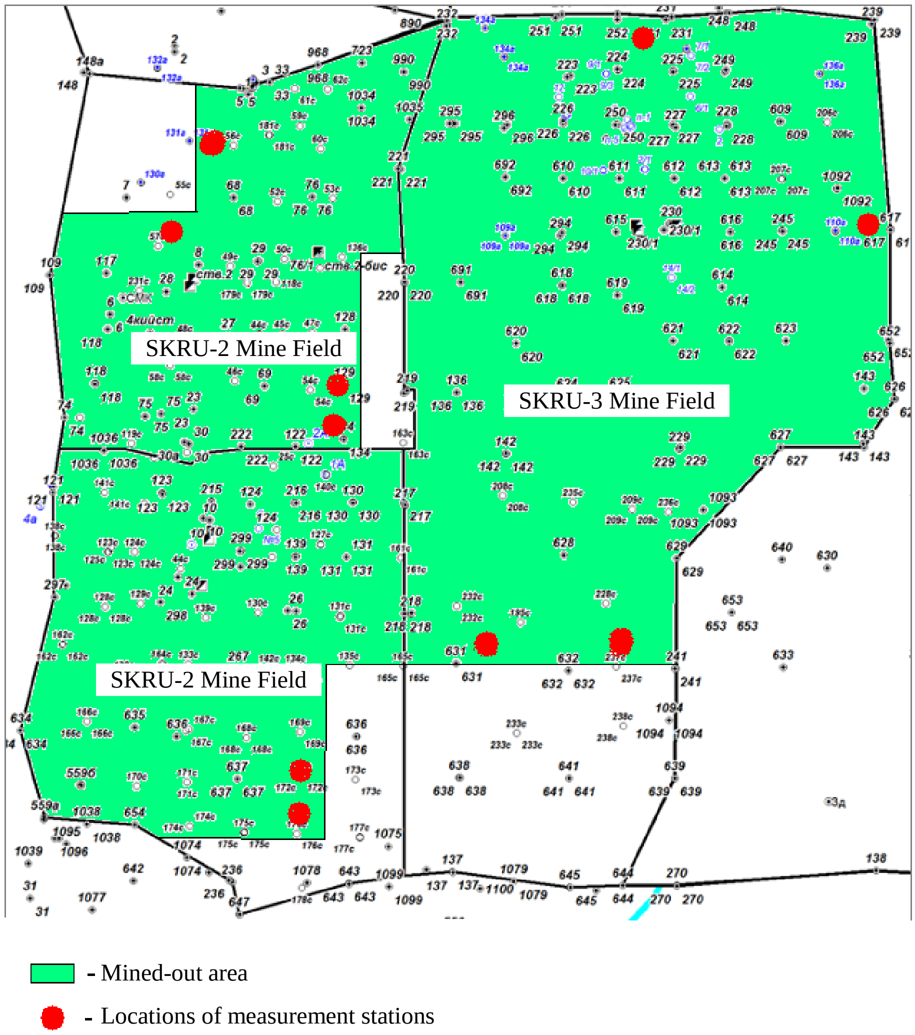

Figure 1. Arrangement of measurement stations in the fields of mines SKRU-1, SKRU-2 and SKRU-3.

In order that the calculation procedure of the actual stresses was applicable, in the proposed design of a measurement station (Figure 2), three differently directed wells were drilled in the orthogonal plane of the axis of an underground excavation: one well was drilled strictly vertical (in line of supposed orientation of one of the principal stresses), and the other two wells was inclined at the angles of 30 and 60 deg to horizon in order to ensure removal of drill cutting from the well. With a view to ensuring a preset direction of the hydrofracture, in the well wall a disk initiation split was made orthogonally to the well axis in the zone between packers using a special device—splitter [2].

During the hydraulic fracturing stress measurement, we recorded: P_c—breakdown pressure; P'_s—shut-in pressure; P_r—reopening pressure; P''_s—shut-in pressure under the second loading; P'_r—reopening pressure under the third loading; P'''_s—shut-in pressure in the third loading. The rupture strength of the rock mass was defined as the difference of P_c and P_r.

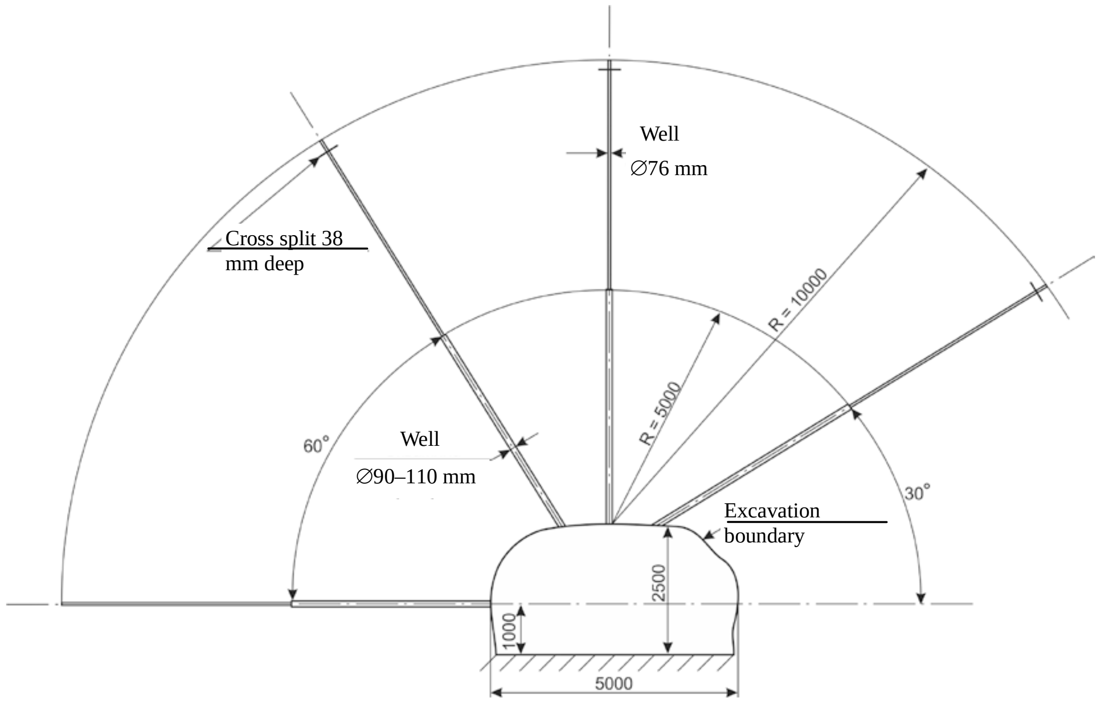

Figure 2. Design of hydraulic fracturing stress measurement station.

The hydraulic fracturing stress measurement is illustrated in this paper y the data from measurement station 8 in SKRU-2 mine. Measurement station 8 was installed in the main haulage way far from the mining front and other excavations, and was not undermined or overmined. The design was as in Figure 2 (one vertical well and two inclined wells). Figure 3 presents the pressure–time diagram plotted during hydraulic fracturing in the well drilled at the angle of 60 deg to horizon at a depth of 10 m from the haulage way boundary.

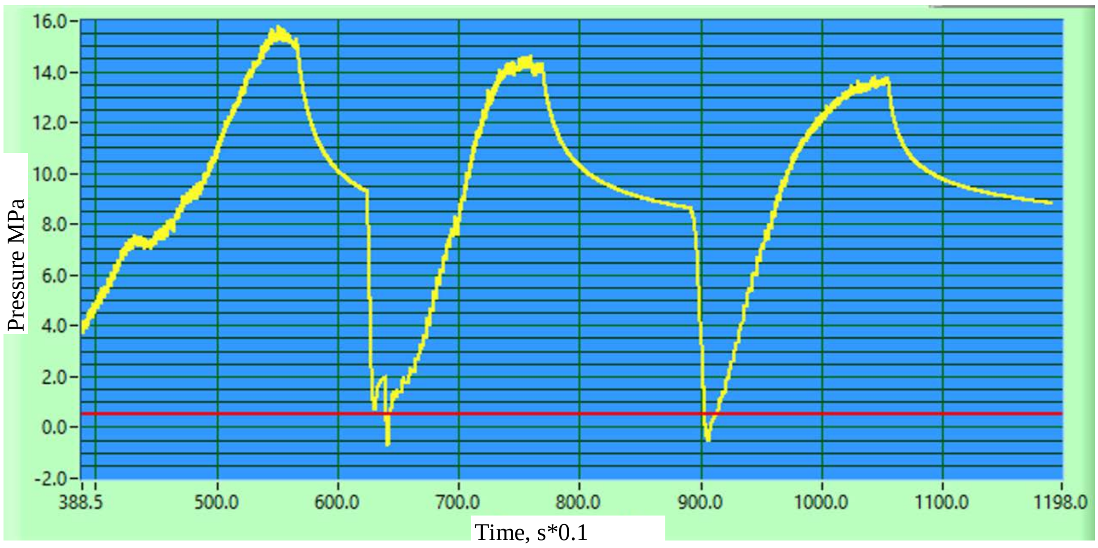

Figure 3. Experimental pressure–time diagram (mine SKRU-2, measurement station 8, well 60°, depth 10 m).

The table 1 below compiles the test data obtained in the three wells of measurement station 8.

Table 1. Hydraulic fracturing stress measurement test log at measurement station 8.

<table>
<tr><th colspan="2">Drilling data</th><th colspan="2">Loading stage 1</th><th colspan="2">Loading stage 2</th><th colspan="2">Loading stage 3</th><th rowspan="2">Rock rupture strength T_c, MPa</th></tr>
<tr><th>Well orientation relative to horizon</th><th>Distance from the haulage way boundary to the fracture</th><th>Breakdown pressure P_c, MPa</th><th>Shut-in pressure P'_s, MPa</th><th>Reopening pressure P_r, MPa</th><th>Shut-in pressure P''_s, MPa</th><th>Reopening pressure P'_r, MPa</th><th>Shut-in pressure P'''_s, MPa</th></tr>
<tr><td>90°</td><td>10.0</td><td>10.8</td><td>6.5</td><td>12.4</td><td>7.4</td><td>11.9</td><td>7.1</td><td>1.6</td></tr>
<tr><td>90°</td><td>9.0</td><td>10.5</td><td>9.0</td><td>13.0</td><td>10.8</td><td>12.5</td><td>10.3</td><td>2.5</td></tr>
<tr><td>60°</td><td>10.0</td><td>15.3</td><td>11.1</td><td>14.3</td><td>9.8</td><td>13.5</td><td>9.7</td><td>1.8</td></tr>
<tr><td>30°</td><td>7.0</td><td>13.1</td><td>9.2</td><td>10.9</td><td>8.6</td><td>10.8</td><td>8.0</td><td>2.3</td></tr>
</table>

After the processing of the experimental data obtained at measurement stations 8 and 7 20 m apart in the SKRU-2 mine field, the actual principal stresses in the salt rock mass were evaluated as: the vertical stress σ_h = 6.7–7.2 MPa, the minor horizontal stress $\sigma_{\min}$ = 9.6–12.4 MPa and the major horizontal stress $\sigma_{\max}$ = 16.4–19.0 MPa.

All in all, in mines SKRU-1, SKRU-2 and SKRU-3 at the Upper Kama deposit 75 hydraulic fracturing stress measurement tests were performed at 8 measurement stations. It is found that the rock mass is subjected to the action of nonequicomponent stress field where the vertical stress is near the calculated value due to the weight of overlying strata and the horizontal stresses exceed the gravity stress by 2–3 times.

The implemented research series proves applicability of hydraulic fracturing in the experimental determination of stress field parameters at deep levels in salt rock masses.

References

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