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# Geodetic Measurements of Underground Gas Reservoirs

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*The size of expected deformations of underground gas reservoirs may be dependent on the volume of gas fullness. According to the proportional gas volume in both of measured gas reservoirs, the technology of geodetic measurements was taken out. Spatial displacements were observed by the method of vertical line, with EDM and vertical movements of monitored points were measured by precise levelling. Together with geodetic measurements, the geological survey was also realized.*

***Key words****: gas reservoirs, precise levelling, spatial displacements, vertical deformation, method of vertical line*

## Introduction

The main function of underground gas reservoirs consists in compensation of the seasonal differences of gas consumption. In summer, the acquired surplus is impressed into the reservoirs, which are vice-versa released in winter. The reservoirs can cover the daily gas variances to ensure the service security of the distributive network. In case of a short-time and long-time gas breakdown, the reservoirs ensure the reliability of gas supply (TASR).

Deformation measurement of the object surface is associated with the determination of subsurface deformations, which indicates a problem of an underlying geological environment. These deformations are not immediately reflected on the geometrical position of structural changes. A new method of measuring subsurface deformation called Time Domain Reflectometry (TDR) has been implemented in the geotechnical problems associated with the slope deformations [2], as well as to measure the subsidence of ground objects and structures of Transportation Engineering [3]. At the future, a variety of use of TDR technology requires calibration with more precise method - like e.g. geodetic measurement.

In winter 2009, the Department of Geodesy of the University of Žilina performs geodetic measurements of two connected underground gas reservoirs to determine possible deformations or shifts of the exposed parts of their construction, caused by volume changes of the compressed gas, height differences of the liquid gas level or temperature changes, which can eventually influence the reservoirs' walls deformations, surface material straining or deformations of their technological facilities.

Geodetic measurements of the both of reservoirs PZ1, PZ2 consist in finding out the spatial and vertical changes caused by mutual gas pumping through the reservoirs. The observation outputs depend on current gas parameters defined by gas level, filling volume and temperature, weight and pressure of gas (Table 1). The deformation values were defined by the comparison of both of observation periods, done in October and November 2009.

*Tab. 1. Physical parameters of the gas reservoirs.*

| | **First observation (October 2009)** | | **Second observation (November 2009)** | |
|---|---|---|---|---|
| | **Reservoir PZ1** | **Reservoir PZ2** | **Reservoir PZ1** | **Reservoir PZ2** |
| **Reservoir total volume** | 500 $m^3$ | 500$m^3$ | 500$m^3$ | 500 $m^3$ |
| **Gas level** | 466,0 mm | 1 993,0 mm | 2 369,0 mm | 422 mm |
| **Temperature** | 11,0 °C | 11,5 °C | 6,5 °C | 9,5 °C |
| **Pressure** | 0,646 MPa | 0,658 MPa | 0,628 MPa | 0,608 MPa |
| **Volume** | 25 127,07 l | 239 638,47 l | 300 207,54 l | 21 081,40 l |
| **Liquid f.+ gas f.** | 19 440,44 kg | 126 952,16 kg | 159 396,83 kg | 17 198,16 kg |

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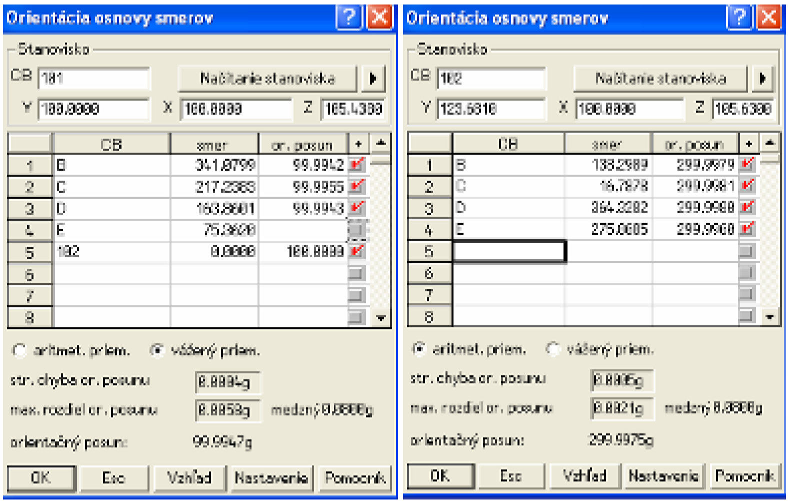
## Observations in Top Section of the Reservoirs Construction

Firstly, the spatial deformations were observed in top section of reservoirs construction, where the maximal deformations were expected. Specifically, it was on the connecting screws, which were situated in the upper parts of four reservoir necks. Four permanent points, signalized by red marks, were stabilized on every of reservoir neck (Fig. 1).

*Fig. 1. Observed points stabilized upon reservoir neck.*

Reference system was based on two reference points 101, 102, which were stabilized in upper part of both of constructions by plastic geodetic marks. Quality of measurements is involved into observation accuracy estimated by measurements in reference system and was defined by angle standard deviation $m_\alpha = 0{,}5\,\text{mgon}$ (Fig. 2).



CB 101

Y 100.0000 X 100.0000 Z 105.4300

|   | CB | smer | or. posun |
|---|---|---|---|
| 1 | B | 341.0799 | 99.9942 |
| 2 | C | 217.2383 | 99.9955 |
| 3 | D | 163.8601 | 99.9943 |
| 4 | E | 75.3620 |  |
| 5 | 102 | 0.0000 | 100.0000 |
| 6 |  |  |  |
| 7 |  |  |  |
| 8 |  |  |  |

○ aritmet. priem. ● vážený priem.

str. chyba or. posunu 0.0004g

max. rozdiel or. posunu 0.0053g medzný 0.0080g

orientačný posun: 99.9947g

CB 102

Y 123.6810 X 100.0000 Z 105.6300

|   | CB | smer | or. posun |
|---|---|---|---|
| 1 | B | 133.2989 | 299.9979 |
| 2 | C | 16.7878 | 299.9981 |
| 3 | D | 364.3282 | 299.9988 |
| 4 | E | 275.0605 | 299.9960 |
| 5 |  |  |  |
| 6 |  |  |  |
| 7 |  |  |  |
| 8 |  |  |  |

● aritmet. priem. ○ vážený priem.

str. chyba or. posunu 0.0006g

max. rozdiel or. posunu 0.0021g medzný 0.0080g

orientačný posun: 299.9975g

*Fig. 2. Accuracy adjustment of angle measurements.*

Sixteen particular points, stabilized upon the reservoirs necks were determined by terrestrial measurements done with total station LEICA TCR 705. Their precise position is defined in Cartesian coordination system in both of period of measurements. The coordination differences Δ*Y*, Δ*X*, Δ*Z*, which were calculated from the both of measurement periods represent 3D shifts of the particular points. The spatial deformation is defined by positional vector estimated according to the equation:

$$p = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}\,, \qquad (1)$$

The particular values of spatial deformation *p* are estimated in millimetres and are involved in the last slope of Table 2.

*Tab. 2. Measurement of the spatial deformations.*

| Point No. | First measurements | | | Second measurements | | | Coordination differences | | | Spatial vector |
|---|---|---|---|---|---|---|---|---|---|---|
| | Y | X | Z | Y | X | Z | ΔY | ΔX | ΔZ | |
| **1** | 96,4233 | 96,0605 | 105,6135 | 96,4244 | 96,0600 | 105,6123 | 1,1 | -0,5 | -1,2 | 1.7 |
| **2** | 96,4235 | 95,5151 | 105,5902 | 96,4246 | 95,5141 | 105,5888 | 1,1 | -1,0 | -1,4 | 1.4 |
| **3** | 95,8089 | 95,6072 | 105,5929 | 95,8081 | 95,6068 | 105,5915 | -0,8 | -0,4 | -1,4 | 1.7 |
| **4** | 95,8758 | 96,0599 | 105,6054 | 95,8766 | 96,0590 | 105,6038 | 0,8 | -0,9 | -1,6 | 2.0 |
| **5** | 95,8859 | 101,5972 | 105,5933 | 95,8873 | 101,5967 | 105,5894 | 1,4 | -0,5 | -3,9 | 4.2 |
| **6** | 96,1209 | 102,3223 | 105,5943 | 96,1211 | 102,3258 | 105,5910 | 0,2 | 3,5 | -3,3 | 4.8 |
| **7** | 96,4033 | 101,7641 | 105,5983 | 96,4047 | 101,7636 | 105,5945 | 1,4 | -0,5 | -3,8 | 4.1 |
| **8** | 96,1193 | 101,5577 | 105,5935 | 96,1219 | 101,5564 | 105,5901 | 2,6 | -1,3 | -3,4 | 4.5 |
| **9** | 128,0685 | 101,8088 | 105,7543 | 128,0662 | 101,8054 | 105,7509 | -2,3 | -3,4 | -3,4 | 5.3 |
| **10** | 128,2378 | 102,3244 | 105,7452 | 128,2358 | 102,3215 | 105,7418 | -2,0 | -2,9 | -3,4 | 4.9 |
| **11** | 128,6853 | 102,2500 | 105,7491 | 128,6827 | 102,2463 | 105,7460 | -2,6 | -3,7 | -3,1 | 5.5 |
| **12** | 128,5841 | 101,6367 | 105,7637 | 128,5811 | 101,6333 | 105,7607 | -3,0 | -3,4 | -3,0 | 5.4 |
| **13** | 128,1599 | 96,0318 | 105,7500 | 128,1576 | 96,0279 | 105,7485 | -2,3 | -3,9 | -1,5 | 4.8 |
| **14** | 128,5612 | 96,2382 | 105,7522 | 128,5585 | 96,2346 | 105,7511 | -2,7 | -3,6 | -1,1 | 4.6 |
| **15** | 128,8510 | 95,6828 | 105,7509 | 128,8486 | 95,6794 | 105,7498 | -2,4 | -3,4 | -1,1 | 4.3 |
| **16** | 128,3298 | 95,5157 | 105,7518 | 128,3274 | 95,5116 | 105,7504 | -2,4 | -4,1 | -1,4 | 5.0 |

## Observations in Technological Part of Reservoirs

Technological part of reservoirs (Fig. 3) is situated behind the abutment wall. Geodetic measurements were performed to indicate the possible deformations influenced by volume of the reservoirs´ filling of gas.

*Fig. 3 Observation in technological part of the reservoirs*

The possible deformations were observed by the method of vertical line, which is based on determination of deviation of particular points from the vertical line realized by two fixed points. Observed points were signalized by adhesive targets bonded on the abutment wall (points 201, 301), on the handle of gas trunk (points 202, 203, 302, 303) and on the lower flange (points 204, 304). Detailed view on technological part of both of reservoirs is in Figure 4.

The distances from the vertical line represent the transversal shifts of the particular points, which were estimated according to the equation:

$$q_i = s_i tg\ \Delta\omega_i \tag{2}$$

The particular values of observed point's shifts are shown in table 3 and 4 for both of reservoirs PZ1 and PZ2. The differences between basic and second measurements are shown in the last slope of the tables in millimetres.

*Tab. 3. Transversal deviations relating to the vertical line of reservoir PZ1.*

| Point No. | First period (F) | | | Second period (S) | | | (F) – (S) mm |
|---|---|---|---|---|---|---|---|
| | *s* | ω | *q* | *s* | ω | *q* | |
| **201** | **5.918** | **0.0000** | **0.0000** | **5.915** | **0.0000** | **0.0000** | **0.0** |
| **202** | **5.550** | **399.9624** | **-0.0033** | **5.550** | **399.9613** | **-0.0034** | **-0.1** |
| **203** | **5.550** | **399.7978** | **-0.0176** | **5.548** | **399.7959** | **-0.0178** | **-0.2** |
| **204** | **4.446** | **399.6804** | **-0.0223** | **4.445** | **399.6762** | **-0.0226** | **-0.3** |

*Tab. 4. Transversal deviations relating to the vertical line of reservoir PZ2.*

| **Point** | **First period (F)** | | | **Second period (S)** | | | **(F) – (S)** |
|---|---|---|---|---|---|---|---|
| **No.** | ***s*** | **ω** | ***q*** | ***s*** | **ω** | ***q*** | **mm** |
| **301** | 6.024 | 0.0000 | 0.0000 | 6.026 | 0.0000 | 0.0000 | 0.0 |
| **302** | 5.740 | 399.9259 | -0.0067 | 5.741 | 399.9247 | -0.0068 | -0.1 |
| **303** | 5.743 | 399.8943 | -0.0095 | 5.747 | 399.8924 | -0.0097 | -0.2 |
| **304** | 4.527 | 399.7192 | -0.0200 | 4.530 | 399.7105 | -0.0206 | -0.6 |

*Fig. 4. Detail of the technological sector of the both of reservoirs PZ1 a PZ2.*

## Vertical Observations in Top Section of Reservoirs

Top section of the reservoirs was also observed by the method of precise levelling with digital level LEICA NA 3003 with its accessories to determine the vertical deformations of the constructions. The technology of measurement was based on the determination of vertical differences between reference system and observed points, which were stabilized upon the revealed reservoirs construction. Vertical shifts of the constructions were then estimated from the height differences between the first and second period of measurements, related to the height level of reference system.

Reference system composed five points stabilized in the surroundings of the reservoirs. The stability of the system was estimated by the comparison of vertical displacements with the tolerance, which is involved in $t = 2$ multiply of height standard deviation, with the probability $\alpha = 0{,}05$ (Tab. 5):

$$\Delta h > 2.m_{\Delta h}$$
$$m_{\Delta h} = m_0 \sqrt{2L} \tag{3}$$

*Tab. 5. Verification of the stability of reference system.*

| | **First period ($m_0$ = 0,24 mm)** | | | | **Second period ($m_0$ = 0,25 mm)** | | | |
|---|---|---|---|---|---|---|---|---|
| | **1001-1003** | **1003-1004** | **1004-1005** | **1005-1006** | **1001-1003** | **1003-1004** | **1004-1005** | **1005-1006** |
| **Δh [mm]** | 0,01 | 0,05 | 0,07 | 0,12 | 0,02 | 0,03 | 0,07 | 0,10 |
| **$2m_{\Delta h}$** | 0,13 | 0,10 | 0,12 | 0,13 | 0,11 | 0,09 | 0,10 | 0,11 |

Observed points were stabilized in the top part of the reservoirs´ construction where the maximal deformation was expected, namely, in every reservoir neck (yellow marks in Figure 1) and in the hanging control caps. The vertical differences between the both of periods are listed in the Table 6.

*Tab. 6. Vertical shifts between the first and second period.*

| | **Hanging control caps** | | | | **Reservoirs´ necks** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Reservoir** | 1 | 2 | 3 | 4 | 21 | 22 | 23 | 31 | 32 | 33 |
| **PZ1** | -2,3 | 0,0 | -0,6 | -0,3 | -1,1 | -1,5 | -1,5 | -1,1 | -1,2 | -1,1 |
| **Reservoir** | 5 | 6 | 7 | 8 | 11 | 12 | 13 | 41 | 42 | 43 |
| **PZ2** | 3,1 | 2,9 | 3,0 | 3,6 | 1,7 | 0,9 | 1,7 | 1,1 | 1,1 | 1,1 |

## Contribution

In respect of the great experience with the deformation measurements, the estimated deformation of gas reservoirs can be considered to be significant with an application of statistical hypothesis testing. Defining the null hypothesis against an alternative one

$$\begin{aligned} & H_0 : \Delta = 0 \\ & H_1 : \Delta \neq 0 \end{aligned} \qquad (4)$$

we are able to judge the construction deformation $\Delta$ with respect to the critical value $m_p$. Null hypothesis is confirmed, when an inequality exists

$$\Delta \leq m_\Delta$$

On the other side null hypothesis is not accepted if

$$\Delta > 2m_\Delta$$

where $m_\Delta = m_p = 0{,}5$ mm is equal to the spatial standard deviation estimated from the observations in top section of reservoirs

$m_\Delta = m_q = 0{,}2$ mm is equal to accuracy of determination of transversal shifts estimated from the measurements in technological part of reservoirs

$m_\Delta = m_{\Delta h} = 0{,}2$ mm is height standard deviation estimated from the precise levelling.

The both of periods of measurements were realized under two alternatives, the first one represents the situation where the left reservoir was released and the second one was full and the second one was not the case. Summarizing both of cases, the left end of reservoirs construction seems to be in moving. The estimated vertical deformations 2 - 4 mm does not indicate to the meaningful motions in the base layers of the reservoirs. On the right sides of reservoirs, the deformations are not confirmed, too.

Realized observations confirm that up to now acquired deformations are in the frame of construction tolerances, but the tendency and direction of the measured deformation vectors seems to be notable. For the purpose of obtaining more objective results, long-time observations are necessary.

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