

EVALUATION OF *IN SITU* STRESSES BASED ON THE SURFACE DISPLACEMENT

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ABSTRACT

Evaluation of *in situ* stresses is one of the most important aspects of any underground project. This paper analyses the existing methods of evaluation of *in situ* stresses along with a method of evaluating the ratio of horizontal and vertical stresses *in situ* by surveying the movements of surface rock. This method of evaluating *in situ* stresses emerged during the analysis of the surface movement due to the excavation of a barrier pillar between two panels filled with cemented backfill at an operating mine in Central Kazakhstan. The findings offered a simple and efficient method for estimation of *in situ* stresses based on the surface subsidence analysis. The method has been practically validated at three mines with various angles of the dip of orebody. Also it helped to estimate rock pressure in coal mines with various steepness of seams, from flat to 70 degrees. The findings offered a simple and efficient method for estimation of *in situ* stresses based on the surface subsidence analysis.

1 INTRODUCTION

It is paramount to know the ratio between horizontal and vertical *in situ* stresses for solving geotechnical problems. Most common international methods of defining the stresses are based on the measurements of movements and deformations of rock mass due to excavations and subsequent creation of cavities (e.g.: bore holes; mine workings; etc.) The smaller the size of the cavity, the smaller the size of rock mass relevant to the measurements. Therefore, the most substantial results that characterise the *in situ* stress field for the entire deposit can only be obtained through the measurement of large bases. These methods of stress calculation were developed in the former USSR by N.P. Vlokh, A.D. Sashurin (Vlokh, 1970), A.V. Zubkov (Zubkov, 2001). The major drawback of these methods is the necessity to know the deformation moduli based on the measurements of movements.

2 ALTERNATIVE METHOD

It is also possible to evaluate the ratio of horizontal and vertical stresses *in situ* by surveying the movements of surface rock.

This method of evaluating *in situ* stresses emerged during the analysis of the surface movement due to the excavation of a barrier pillar between two panels filled with cemented backfill at Mine №57 of Zheskazgan in Central Kazakhstan. Right above the pillar there was a mine railway that transported ore to the processing plant. It was identified that the centre of surface deformation had moved towards the strike. The result was unexpected. Numerical modelling of the situation through the finite element analysis has shown (Figure 1) that the deviation of the movement zone under shallow dip angles (5-9°) is linked to a high horizontal tectonic stress magnitude *in situ*. In the area of the Mine №57 these stresses exceed 3-4 times the vertical gravitation pressure.

Solving a problem of the elasticity theory to define deformations around an inclined thin slot resulted in a finding that the location of the line of maximum deformation depends on the natural stress field (Muskhelishvili, 1966). In most cases the vertical ground pressure at a depth H can be taken as equal to γH , where γ is the bulk density of the roof material. The ratio between horizontal and vertical stresses *in situ* is characterised by a coefficient λ . As follows from a simple analytical model, the deviation grade β of the line of maximum displacement from a perpendicular to the dip can be calculated using the following formula, where α - is the angle of the orebody dip:

$$\beta = \arctan[(1-\lambda)\sin 2\alpha / (\cos^2 \alpha + \lambda \sin^2 \alpha)]/2 \quad 1)$$

The correlation between the deviation grade β , the natural stresses *in situ* and the dip angle is shown in Figure 2. If the side *in situ* stresses coefficient $\lambda > 1$ (horizontal stress exceeds vertical) the line of maximum rock movements deviates from the normal towards the dip of the orebody (β grade is negative). If $\lambda < 1$ (horizontal stress is lower than vertical) the line of maximum rock movement deviates from the normal towards the rise of the orebody (β grade is positive).

Under the hydrostatic distribution of natural stress *in situ* ($\lambda = 1$) maximum the rock movements of the ground affected by mine workings are developing perpendicular to the dip of the orebody ($\beta = 0$).

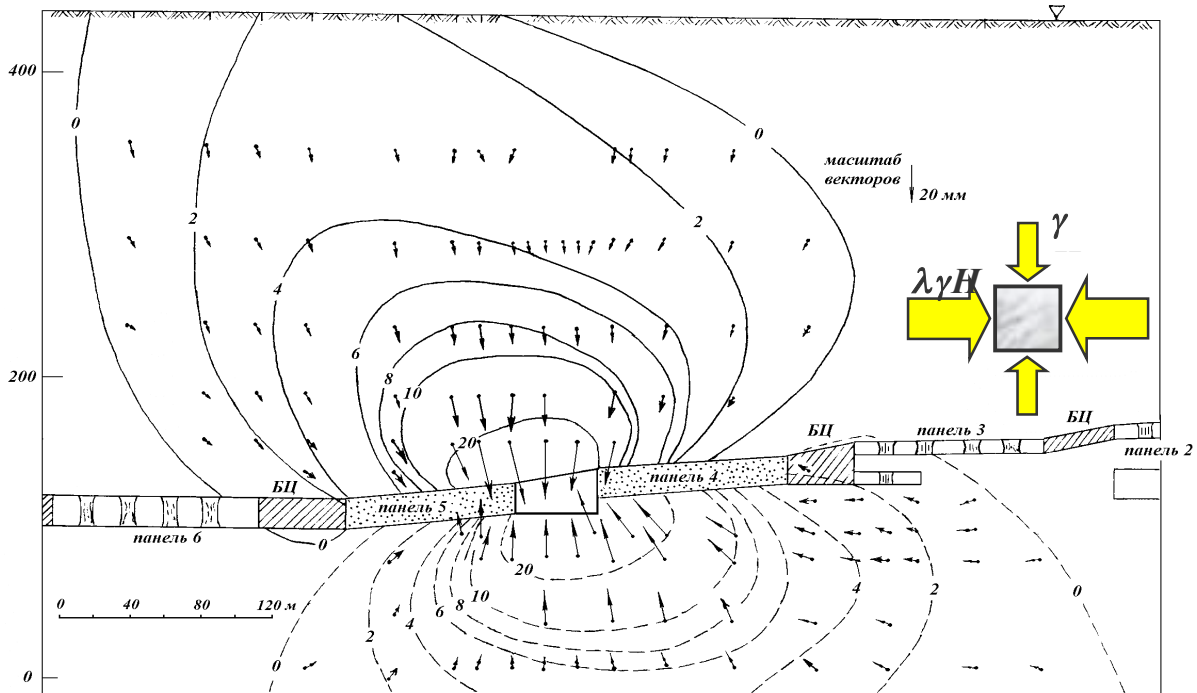


Figure 1: Vectors and isolines (mm) of the rock movement during excavation of a pillar as a result of the numerical modelling.

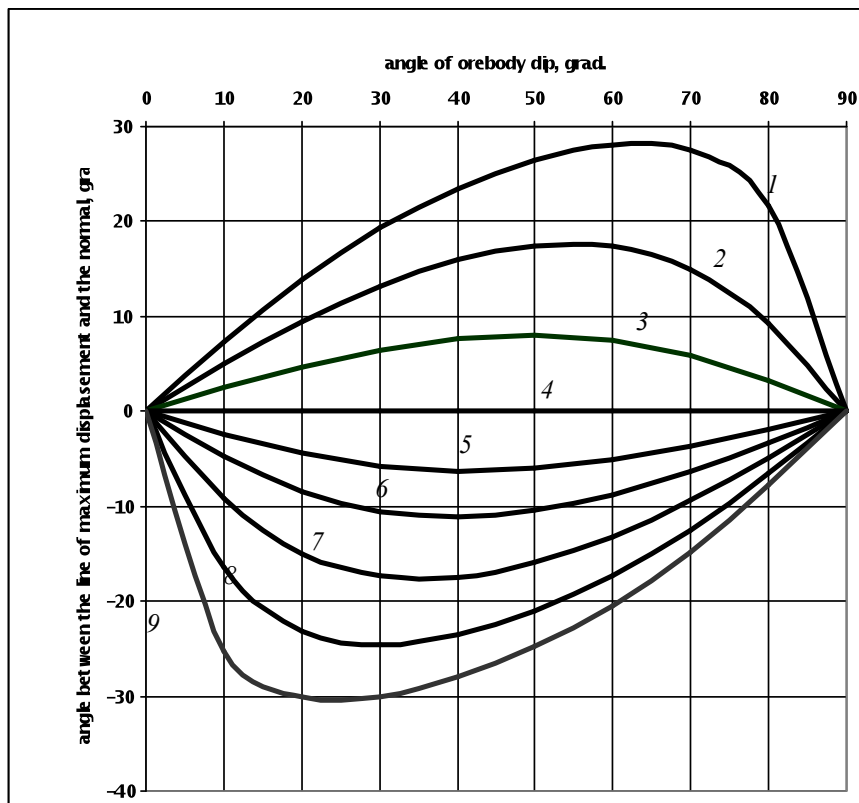


Figure 2: Relationship between the angle β depending on the dip angle and the natural stress ratio in rocks:
 1) $\lambda = 0.25$; 2) $\lambda = 0.5$; 3) $\lambda = 0.75$; 4) $\lambda = 1$; 5) $\lambda = 1.25$; 6) $\lambda = 1.5$; 7) $\lambda = 2$; 8) $\lambda = 3$; 9) $\lambda = 5$.

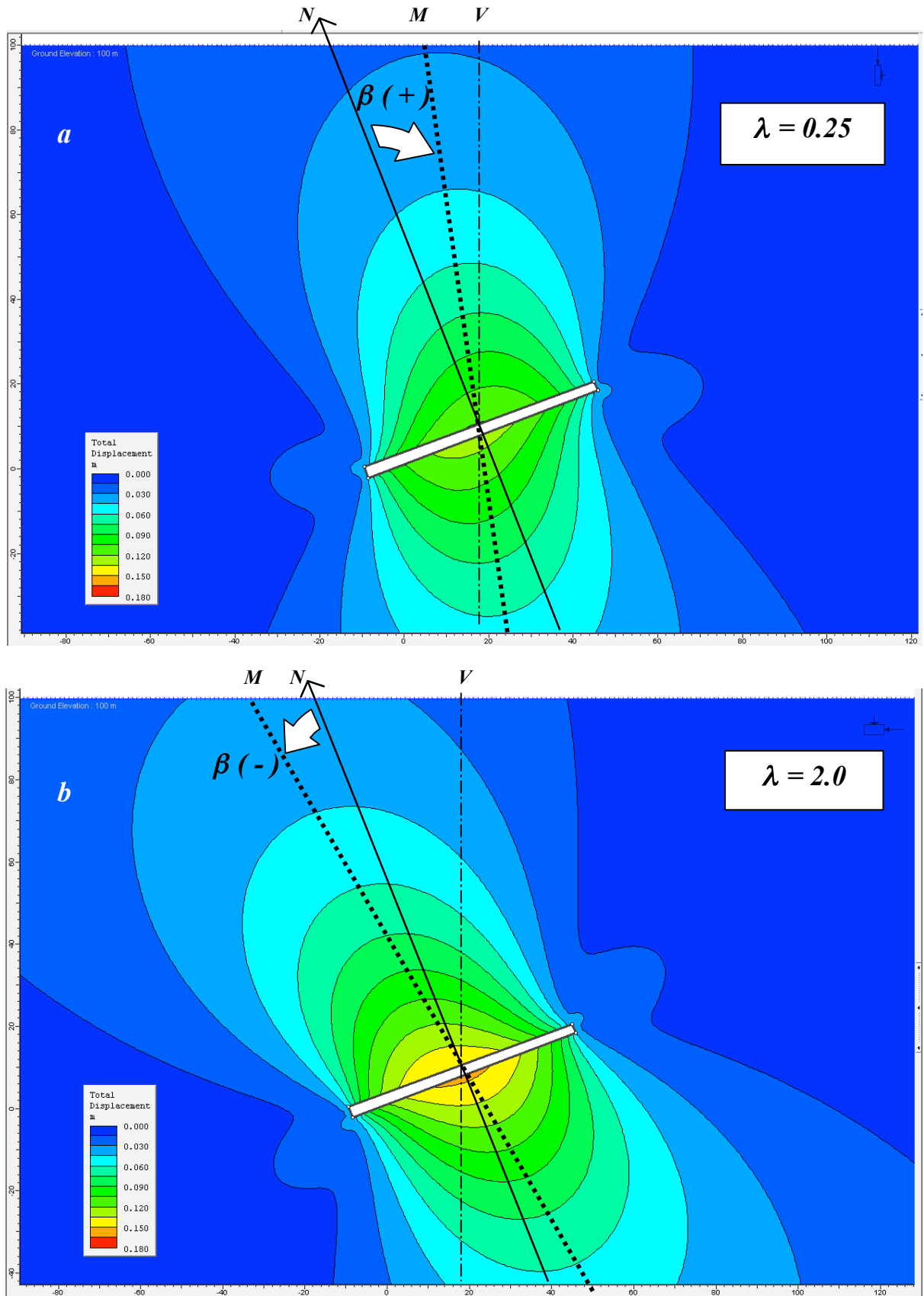


Figure 3: Influence of *in situ* stress field on development of displacements.

These patterns can also be shown by numerical modelling. Figure 3 shows displacement of rock mass caused by an inclined mine working under two different values of horizontal stress:

- $\lambda = 0.25$ – there are no tectonic stresses in rock; horizontal stresses are being created by $\lambda = \nu/(1 - \nu)$, where $\nu = 0.20$ - Poisson's ratio. Figure 3a shows that the zones of most movements and the line of maximum displacement M are developing above and below the excavation with deviation from normal N to the dip towards vertical V , however do not reach it. The β grade is positive.
- $\lambda = 2.0$ – there are high tectonic stresses in rock (Figure 3b). The zones of major movements and the line of maximum displacement M deviate from normal N to the dip and move apart from the vertical V . The β grade is negative.

Surveying the surface movements allows for the point of maximum subsidence to be identified, so the line of maximum deformation can be defined on a cross-section. Its position regarding the perpendicular N to the dip of the orebody defines the value of the β grade. The horizontal to vertical stress ratio λ along the dip of the orebody α can be calculated by this equation:

$$\lambda = \frac{\sin 2\alpha - 2 \tan \beta \cdot \cos^2 \alpha}{\sin 2\alpha + 2 \tan \beta \cdot \sin^2 \alpha} \quad (2)$$

The method offered allows for estimation of the *in situ* stress fields at the Irtyshskiy and Orlovskiy polymetallic deposits in Eastern Kazakhstan mined by Kazkhmys Corporation (<http://kazakhmys.com>).

Surveys of the surface displacements at the Irtyshskiy Mine were completed by S.N. Zelentsov (VNIMI). The profile line of the axis of the exploration mine shaft defines the surface subsidence. The drifts at three different levels are given *in situ* vectors of movements of the footwall of the orebody mined with backfill (Figure 4).

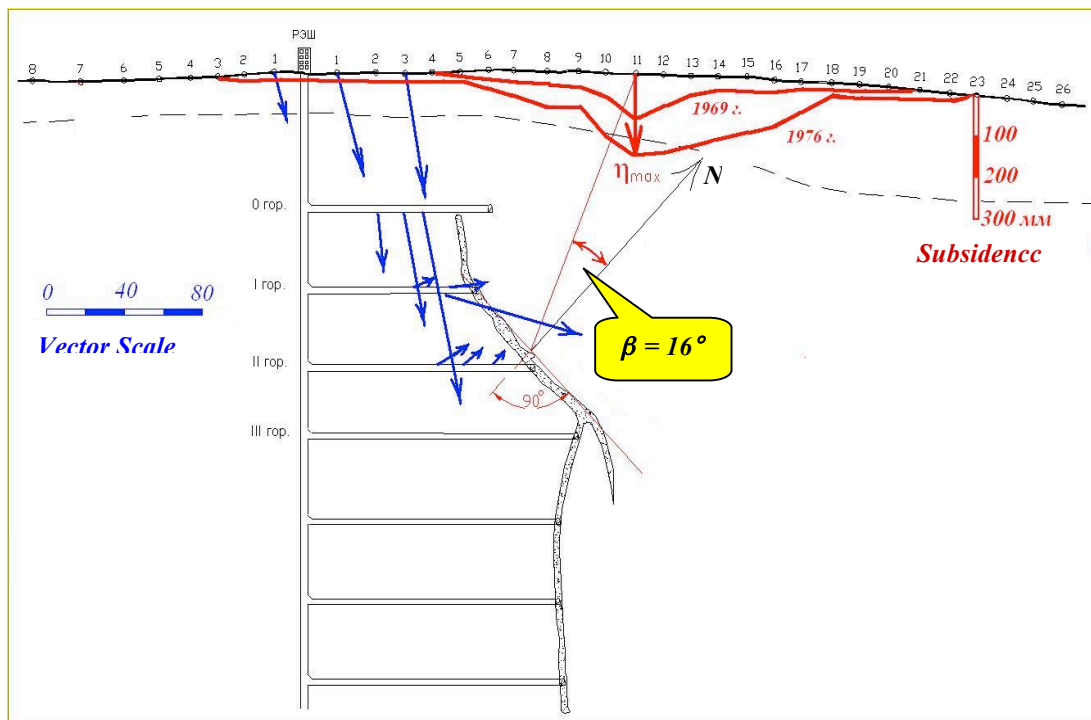


Figure 4: Movement of rock mass at the Irtyshskiy Mine.

The normal N drawn from the centre of the mined out space intersects the surface at the benchmark 16. The maximum surface subsidence η_{max} was registered at the benchmark 11, i.e. the line of maximum subsidence deviates from normal N upright at the grade $\beta = 16^\circ$. This means that the *in situ* stress ratio $\lambda < 1$.

The dip angle is $\alpha = 50^\circ$. Using the Equation (2) we receive the *in situ* stresses coefficient for the Irtyshskiy Mine $\lambda = 0.6$ along the dip of orebody.

3 VERIFICATION

To check the result, numerical modelling was conducted for the current situation under various horizontal stress coefficient λ . The highest coincidence between the modelling and surveying of the rock movements has been achieved when the coefficient $\lambda = 0.6$ (Figure 5).

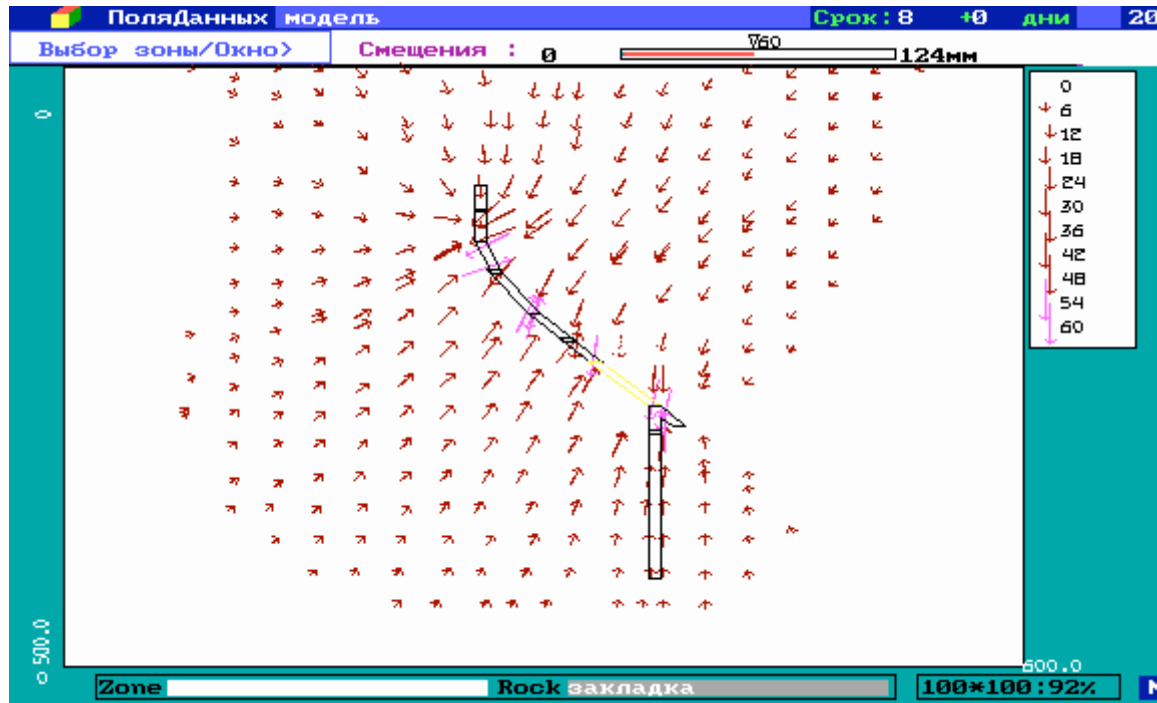


Figure 5: Numerically modelled displacement when $\lambda = 0.6$.

The vectors of movement are indicative of the footwall of the orebody (Figures 3 and 4). They mirror those of the hangingwall becoming negative. During field measurements at the level 0 mostly downward movements were registered. In a drive at level 1 the vectors of displacement are practically horizontal and faced towards the mined out space.

In a drive at level 2 an underground profile line registered uplifting of the rock mass and its movement towards the mined out space. Similar changes of directions of rock mass movements were obtained in the numerical model (Figure 5) when using the *in situ* stress ratio $\lambda = 0.6$.

The conclusion that at the Irtyshskiy Mine the horizontal stresses across the strike are lower than the vertical stresses in general is confirmed by the type of rock failures in mine workings.

The Orlovskiy Mine of rich polymetallic ores is being mined with backfill. The surface subsidence is being controlled via a profile line of the mine shaft axis across the strike.

The measurements of surface subsidence are shown in Figure 6. The maximum subsidence falls at the benchmark 10.

The location of this benchmark corresponds to the point where normal N joins the surface when drawn from the centre of the mined out space of the orebody 1. Thus the surface subsidence shows a hydrostatic character of the natural stress field at the Orlovskiy Mine.

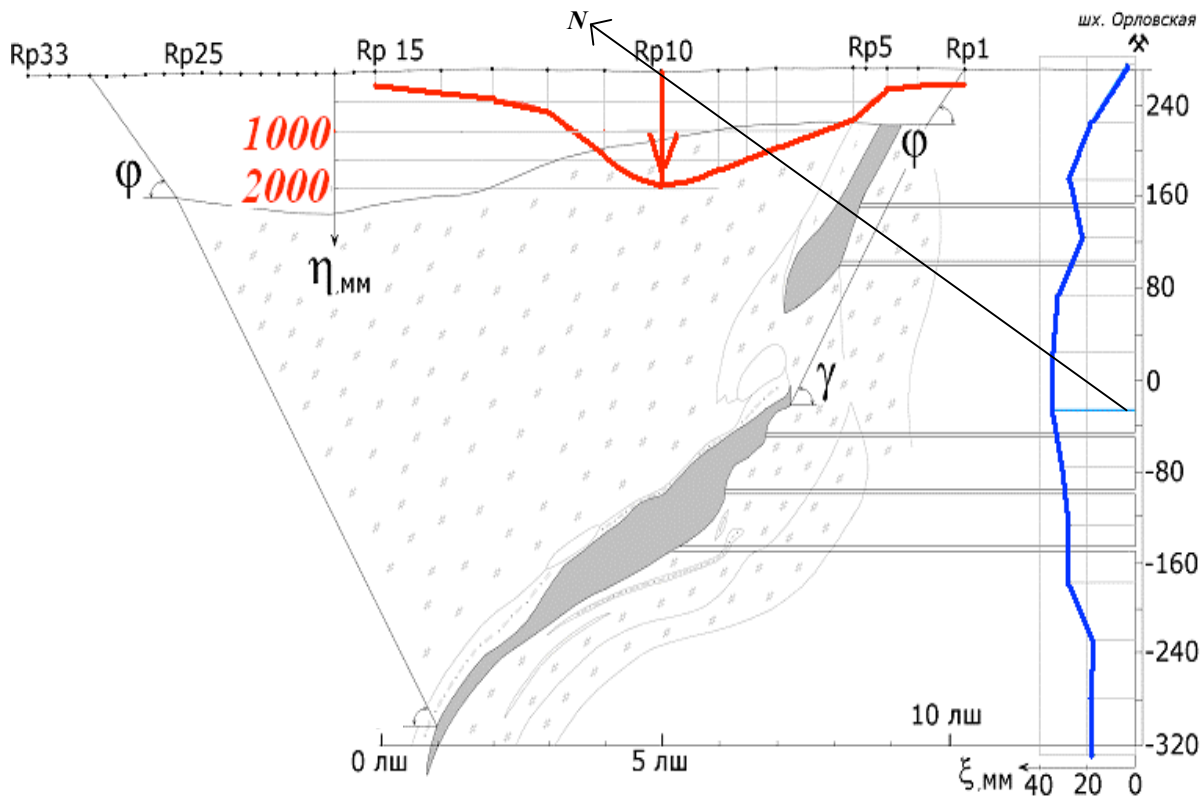


Figure 6: Vertical and horizontal movements at the Orlovskiy Mine.

For estimation of the horizontal deformations of the footwall one can use a mine shaft for a vertical profile line. Its axis is regularly controlled through alignment of liners. The results of the alignments can show a pattern of change of the horizontal movements in depth and a process development in time. A special purpose use of the shaft alignments can take place when mining steeply dipping orebodies, as the horizontal stresses dominate here over the vertical ones. Figure 6 shows the movement of the shaft axis at the Orlovskiy mine obtained through the alignment survey. The maximum horizontal deformation of the footwall is observed at RL30. This corresponds to the mirror image of the strike surface normal drawn from the centre of the mined out top orebody. It can therefore be concluded that distribution of horizontal deformations corresponds to hydrostatic distribution of stress *in situ*.

Also this conclusion is confirmed by visible signs of rock stresses in the mine workings. The main signs are:

- equal intensity of rock stress is shown in mine workings in all directions, i.e. vertical, horizontal and multidirectional l.
- equal intensity of failure of different parts of mine workings, i.e. roof, floor, face and walls.
- equal intensity of core dinking from prospective holes of different directions.

This displays that the rock stress distribution *in situ* at the Orlovskiy Mine is close to hydrostatic, i.e. the horizontal stresses are approximately equal to the vertical ones.

A large amount of mine subsidence studies is being done at coal mines. Figure 7 shows the processed data of Yu.V.Posyl'nyi study (Posyl'nyi, 2000) of surface subsidence due to coal mining in Donbass (Southern Russia). The depth of workings varied from 80 m to 300 m and dip angle varied from 0° to 68°.

Using formula (2) the *in situ* stress ratio λ was calculated along the dip of coal seams. The results are shown in Figure 8 and are based on 74 observations that established an average ratio for Donbass coal mines $\lambda = 0.85$ with square root deviation of 0.29 (variation coefficient 34%).

This displays that the *in situ* stress in coal mines is close to hydrostatic, as the gravitation pressure γH is close to the rock mass strength.

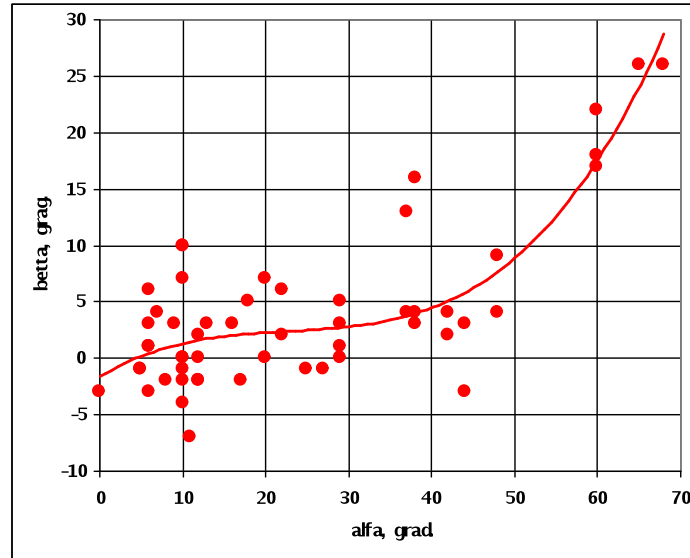


Figure 7: Dependence of the deviation angle β (beta) from the seam dipping angle (alfa) in Donbass.

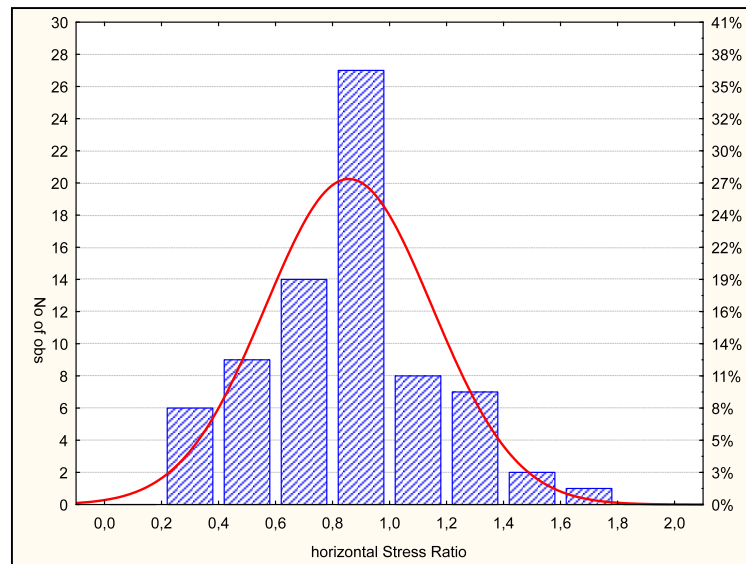


Figure 8: Distribution of values of the *in situ* stress ratio in coal mines of Donbass.

4 CONCLUSIONS

The findings offered a simple and efficient method for estimating *in situ* stresses based on surface subsidence analysis. The method has been practically validated at three mines with various angles of the dip of orebody. Also it helped to estimate rock pressure in coal mines with various steepness of seams, from flat to 70°. The *in situ* stress ratios calculated with this method are consistent with the signs of rock pressure in underground mine workings in hard rock.

5 REFERENCES

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