PHOTOGRAMMETRIC MEASUREMENT OF A BORING TOWER

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Introduction

A boring tower is a part of a drilling rig. Load of a rig as well as depth of drilling depend mainly on construction of a boring tower. Proper distribution of stresses in it's elements is main condition for a long work without break downs.

Dr. Andrzej Sołtysik and his co-workers from Academy of Mining and Metallurgy, Cracow have developed a method for determination of boring tower strength. Basing on known stresses, occuring in tower segments, one can determine fatigue strength of a tower construction .To do that it is necessary to know a magnitude of deformation of tower elements for variable load.

Photogrammetric measurement appears to be the most suitable to determine the deformation.

Apart from the determination of the tower deformation, it is also possible to determine correctness of tower assembling as well as stresses of stay ropes. During series of observations the tower is effected by changing load coming either from drill rod or caused artificially. In addition: a quality of welds are examined magnetically, a thickness of pipe elements are measured by ultrasonic method and detailed visual inspection is performed. These data gives us a complete information about a boring rig condition.

The method of measurement

State of object in 5-6 phases are recorded by photogrammetric method and then the deformation of tower's elements are determined. For that purpose horizontal displacements of sixty points are determined.

Photographs are taken simultaneously by Photheo 19/1318 camera from stations A and B. Synchronization of exposure was obtained by using walky-talky. Location of camera stations against boring tower should set up a good condition for intersection. It mean that camera axis should intersect at 90°.

For each cameras three control targets (11,12,13 and 21,22,23 - fig.1) should be established. Control points 11,13 and 21,23 are located near the photo frame, and have the some high as the projection center. On each photos they determine a horizontal line.

These control points are used for correction of angular orientation elements of taken photos. Linear orientation elements are stable as camera is firmly set up on stations. In the field there are measured: length of the base and angles between base and the control points 12 and 22.

It is important to develop negatives in such a way that, by decreasing contrast and maximal density of negative, the influence of edge phenomena is limited.

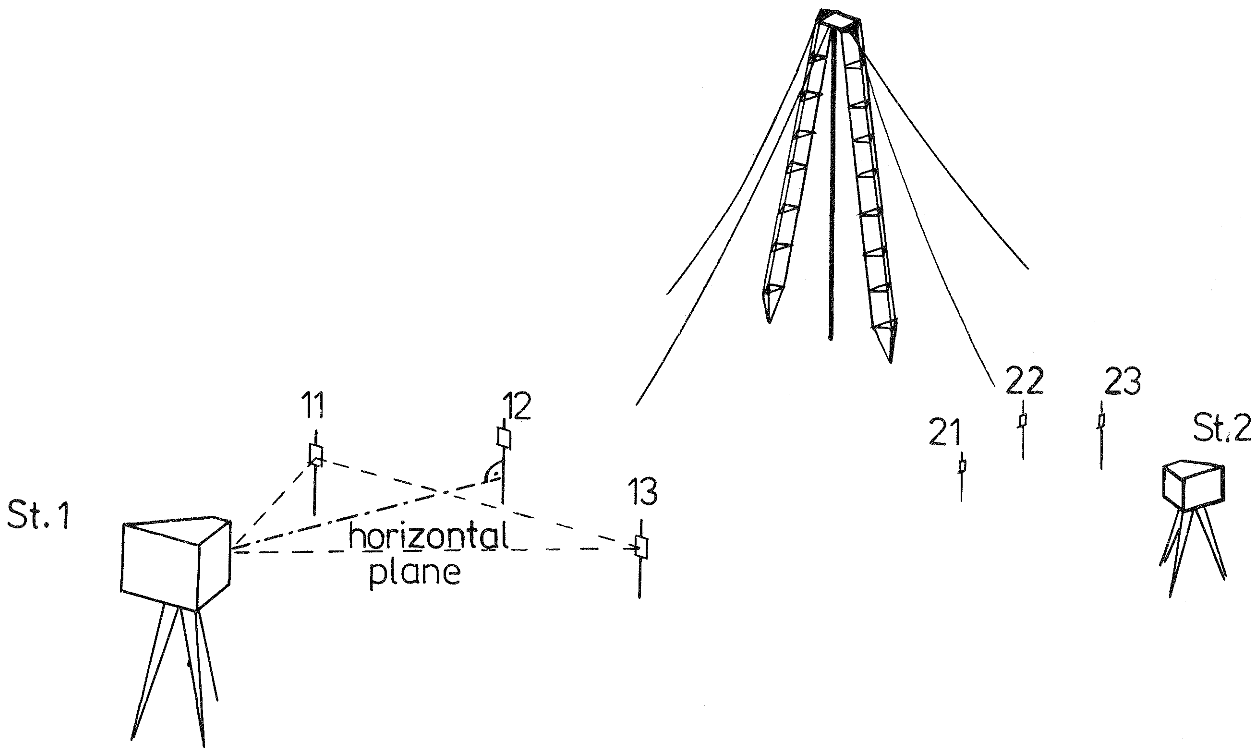

Fig.1 Mutual arrangement of camera stations, control points and the boring tower

For photograms measurement a precise stereocomparator Stecometer was used. The photos of succesive phase were combined in the following time-pairs: 1-2, 3-2, 3-4, 5-4, 5-6, 1-6, 1-4 (for 6 phases). Such method of measurement gives an opportunity to check results and to estimate an accuracy. According to our experiences some systematic and personal errors are eliminated by using such measuring procedure.
Negatives are oriented along the fiducial mark line or along a line of an artificial horizon (lines: 11-13, 21-23). The following sets of points are measured: the fiducial marks, the control points and the points located on tower's elements. The measurement of the control points is repeated after tower measurement. To minimalize an influence of photochemical image deformation it is very important to chose observed points properly. Mostly the points are chosen on both edges of steel pipe on different hights. The same background should appear on both sides of tower elements because of light and shade effects. Due to this limitation it is sometimes impossible to measure displacements in places, which are critical from the experts' report point of view.

The basic measured values are the horizontal time parallaxes $p = x' - x''$. Vertical parallaxes q are also measured but generally not used (besides for control points 11,13,21,23).

The differences in the vertical paralaxes gives us information about precision of measurement.

Two methods of time-pair observation appears to be of the same accuracy: stereoscopic observation and seperate mono observations of the left and right photos. We should realize that in stereoscopic observation it is easy to make error caused by variability of light - and - shadow effects occuring differently on both photos.

Calculation of displacements

Measured values for a given point P corrected due to camera orientation errors according to the formulae:

$$p_P = p'_P + \frac{q'_{13} - q'_{11}}{x'_{13} - x'_{11}} \cdot z'_P + \cos^2\gamma \cdot p_{12} \qquad (1)$$

$$x_P = x'_P + \frac{z'_{13} - z'_{11} + q'_{13} - q'_{11}}{x'_{13} - x'_{11}} \qquad (2)$$

where: x', z', p', q' - measured image coordinates and parallaxes

$$\gamma = \operatorname{arc\,tg} \frac{x'}{c_k}$$

$$p_{12} = p'_{12} + \frac{q'_{13} - q'_{11}}{x'_{13} - x'_{11}} \cdot z'_{12} \qquad (3)$$

To calculate components of the observed point displacements and assambling deviations it is necessary to know the aproximate coordinates of the camera stations as well as coordinates of the points. They are calculated from: measured in the field: the length of the base and an angle of the camera orientation, measured on photos image coordinates x' and known c_k. The coordinates are calculated first in the coordinate system of camera station A and then transformed to the local coordinate system of the boring tower.

Time - parallaxes, corrected first according to equation (1), are then adjusted. For each measured point the following time parallaxes are set up:

$$p_{1-2},\ p_{2-3},\ p_{3-4},\ p_{1-4},\ p_{1-6},\ p_{6-5},\ p_{5-4}$$

Adjustment are carried out in the same way as for level circuits (Fig.2) with the weights;

$$p_I = \frac{1}{3}, \quad p_{II} = 1, \quad p_{III} = \frac{1}{3}$$

First the most probable value of $\bar{p}_{1-4}$ is calculated and then corrections, adjusted values of the time - parllaxes and their errors are calculated. The components of measured points displacement (dX_p, dY_p) are calculated from formulae (2):

$$\begin{bmatrix} dX_p \\ dY_p \end{bmatrix} = \begin{bmatrix} \frac{\Delta X_B \cdot d_A^2 \cdot \cos^2 \gamma_A}{a} & \frac{-\Delta X_A \cdot d_B^2 \cdot \cos^2 \gamma_B}{b} \\ \frac{\Delta Y_B \cdot d_A^2 \cdot \cos^2 \gamma_A}{a} & \frac{-\Delta Y_A \cdot d_B^2 \cdot \cos^2 \gamma_B}{b} \end{bmatrix} \cdot \begin{bmatrix} p_A \\ p_B \end{bmatrix} \quad (4)$$

where: $a = c_{kA} \cdot (\Delta X_A \cdot \Delta Y_B - \Delta X_B \cdot \Delta Y_A)$
$b = c_{kB} \cdot (\Delta X_A \cdot \Delta Y_B - \Delta X_B \cdot \Delta Y_A)$
c_{kA}, c_{kB} - camera constances

$\Delta X_A = X_p - X_A \quad ; \quad \Delta Y_A = Y_p - Y_A$

$\Delta X_B = X_p - X_B \quad ; \quad \Delta Y_B = Y_p - Y_B$

$d_A = \sqrt{\Delta X_A^2 + \Delta Y_A^2} \qquad d_B = \sqrt{\Delta X_B^2 + \Delta Y_B^2}$

For all calculations the microcomputer ZX Spectrum was used.

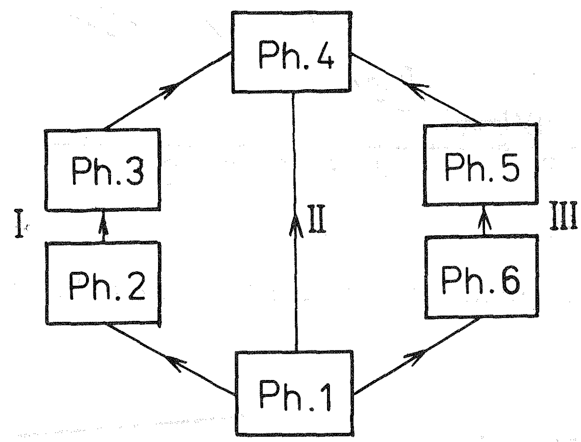

Fig.2 Scheme of the observation adjustment

Results of a boring tower deformation measurements

The components of points displacement, calculated from formula (4), are compared with a standard displacement (calculated for known load and taking into account technical characteristics of the tower).

On fig fig 3,4 the results of measurement are shown.

The mean errors of determined tower displacements in photo scale are as follows:

station A: 1.9 ; 2.1 ; 1.7 ; 2.0 ; 2.1 ; 1.8 [μm]

station B: 2.0 ; 1.4 ; 1.0 ; 1.4 ; 1.2 ; 1.1 [μm]

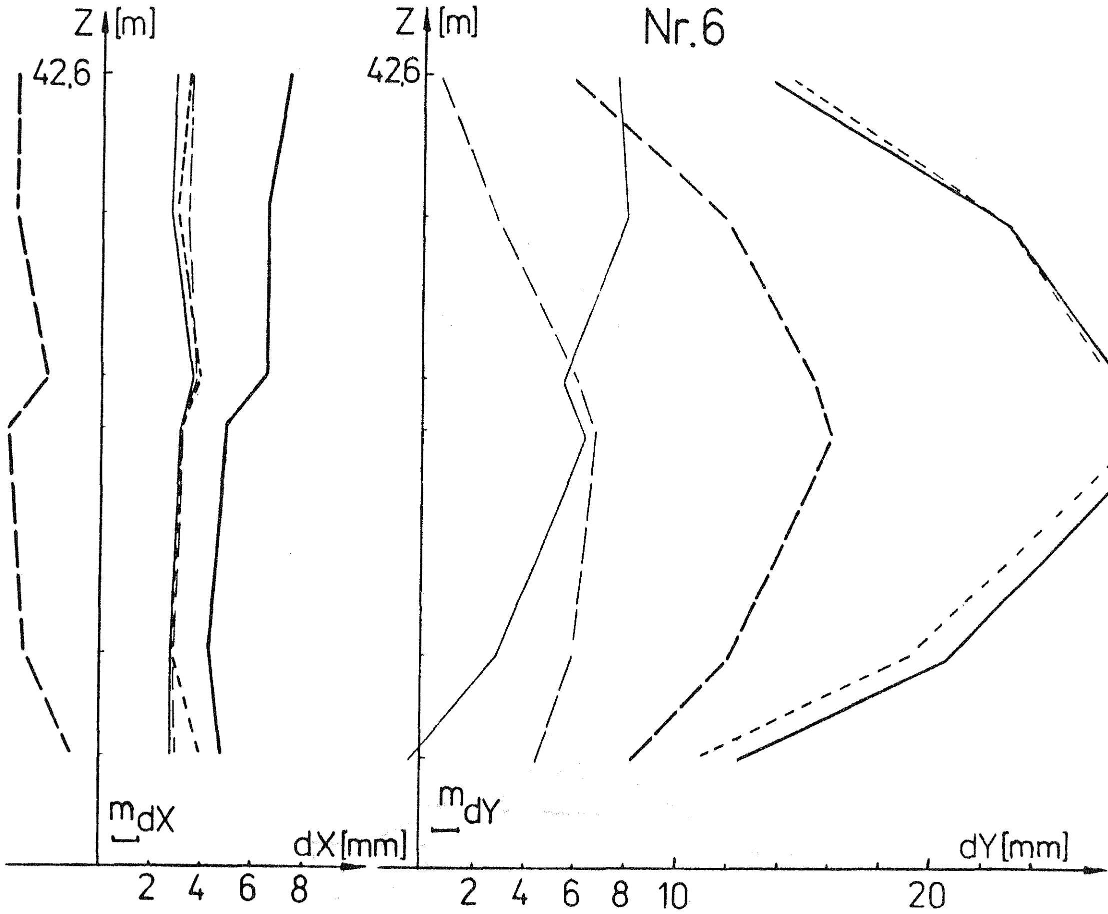

Fig.3. The displacements in vertical planes XZ and YZ.

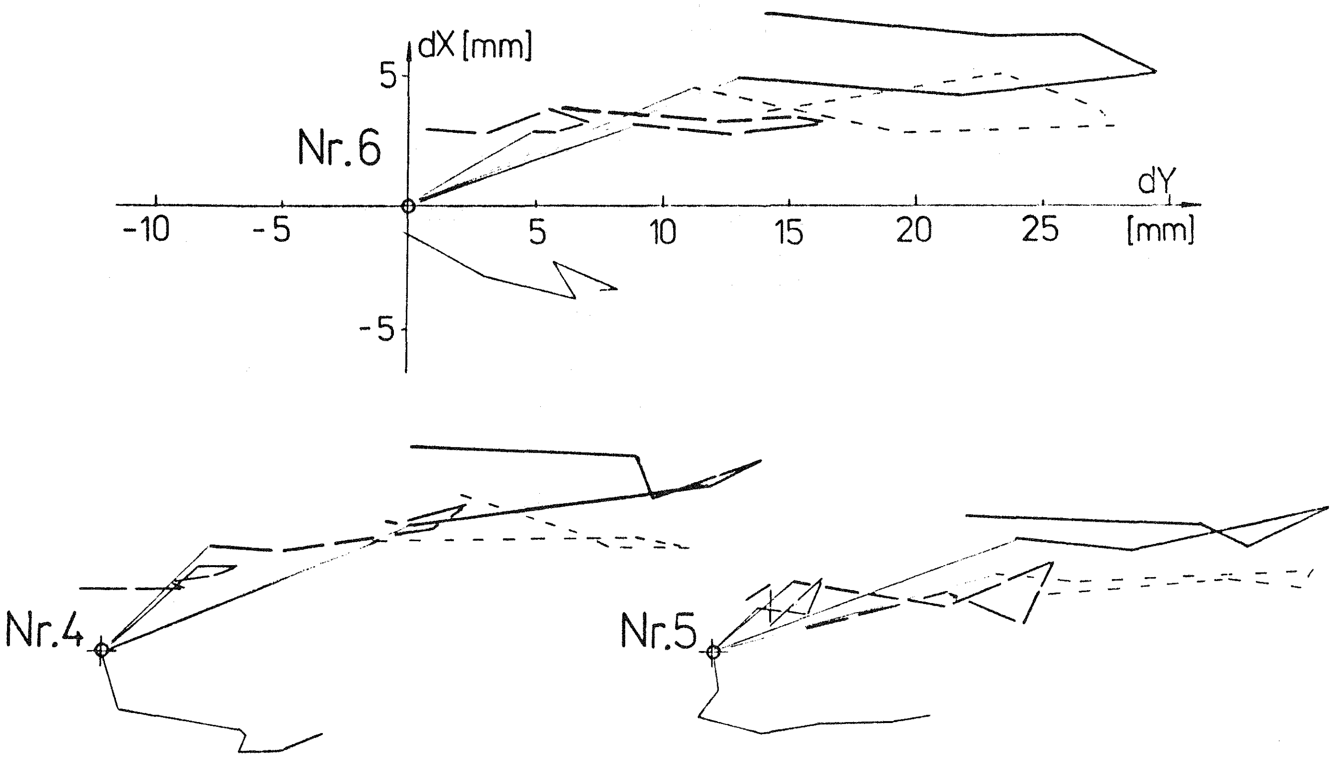

Fig.4. The displacements in horizontal plane XY.

As can he seen from above, that the adjusted time-parallaxes are calculated with mean error equal ± 1.6 μm. It means that the displacement of point are determined with accuracy of ± 1.5 mm.

Determination of the assembling deviations

The assembling deviations are determined for an unloaded tower. During the displacement measurement both generating line of each shears are observed. These data make it possible to determine the shears axes on the photos. The task is solve by approximation using linear function. The plane, to which shear axis belong, can be defined by any two points located in shear axis (on image plane) and projection center. Because such plane is defined in the image coordinate system it must be then transformed to the local tower coordinate system. This transformation is reduced to a rotation in a horizontal plane. The angle of the rotation is equal to the camera orientation angle. Having the planes defined in such a way, for both camera station, the position of shear axis in space can be find as the intersection of these two planes.

In practice the problem has been solved as follows. The shear axis is approximated using least square method by the straigh line pasing through, points located on shear's generating line according to formula:

$$ax + by + c = 0$$

Then the points of intersections of this straigh line with axis x' and z' of image coordinate system are found. These points and projection center O define the plane given by the equation:

$$Ax + By + Cz + D = 0$$

where: A,B,C – the coordinates of the vector $\vec{r}$ orthogonal to that plane

This vector is then rotated about angle which is equal to the camera axes orientation angle:

$$\vec{R} = A\,\vec{r}$$

where: A – is operator of the rotation and

$$A = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The vector $\vec{S}$ of shears' axis is a vector product of $\vec{R}_1$ and $\vec{R}_2$ for the both camera station

$$\vec{S} = \vec{R}_1 * \vec{R}_2 \qquad \vec{S}(Sx, Sy, Sz)$$

Components of deflection of the shear's axis from the vertical line in two vertical planes can be calculated as follows:

$$\sigma_{XZ} = \frac{Sx}{Sz} \qquad \sigma_{YZ} = \frac{Sy}{Sz}$$

The shears 1-2-3 and 4-5-6 are rigidly fastened so the mean deflection of left and right side of boring tower can be determined

$$\sigma^{L}_{XZ} = \frac{1}{3}\cdot(\sigma^{1}_{XZ} + \sigma^{2}_{XZ} + \sigma^{3}_{XZ})$$

$$\sigma^{L}_{YZ} = \frac{1}{3}\cdot(\sigma^{1}_{YZ} + \sigma^{2}_{YZ} + \sigma^{3}_{YZ})$$

$$\sigma^{P}_{XZ} = \frac{1}{3}\cdot(\sigma^{4}_{XZ} + \sigma^{5}_{XZ} + \sigma^{6}_{XZ})$$

$$\sigma^{P}_{YZ} = \frac{1}{3}\cdot(\sigma^{4}_{YZ} + \sigma^{5}_{YZ} + \sigma^{6}_{YZ})$$

For correctly assembled boring tower the deflections should fullfil the following conditions:

$$\left|\sigma^{L}_{XL}\right| = \left|\sigma^{P}_{XZ}\right|$$

$$\left|\sigma^{L}_{YZ}\right| = \left|\sigma^{P}_{YZ}\right| = 0$$

Ifthese contitions are not fullfiled it means that the whole construction is deflected:

$$\sigma_{XZ} = \frac{1}{2}(\sigma^{L}_{XZ} + \sigma^{P}_{XZ})$$

$$\sigma_{YZ} = \frac{1}{2}(\sigma^{L}_{YZ} + \sigma^{P}_{YZ})$$

Taking into account the height of the boring tower the deflection of the upper part of the boring tower is determined:

$$W_{XZ} = \sigma_{XZ} * H$$

$$W_{YZ} = \sigma_{YZ} * H$$

Determination of pull forces of stay ropes

For full estimation of a technical condition of a boring tower it is necessary to determine - besides the values described above - the forces that occured in the places at which stay ropes are fixed to the horing tower . These forces should be determine for various load of a horing tower. The problem lies in determination of parameters of a chain curve which physic model is a stay rope. The parameters of the chain curve can be determined by approximation that is based on photographs of a stay rope. As, the most important are forces. that occur in the places, at which stay ropes are fixed to the boring tower, it is not necessary to have the whole stay rope recorded on the photos; it is sufficient to have recorded only part which lies near the construction. Therefore it is not necessary to take additional photos; the photos taken to determine displacement and deformation of boring tower, on which about 60-90% of the whole stay rope is recorded. Using the same photos is also very advantageous from the point of view of synchronization when recording boring tower for various load.

To solve this problem the coordinates of lower points, at which stay ropes are fixed, as well as the camera stations should be surveyed. The photogrammetric measurements consist in measuring of image coordinates of rope in a few places (minimum 3). The measured image coordinates of the stay rope are then transformed to the vertical plane on which the stay rope lies

$$\vec{r}_t = A\,\vec{r}'$$

where:

$$\vec{r}' = \left[x',\ c_k,\ z'\right]^T$$

$$\vec{r} = \left[x_t,\ y_t,\ z_t\right]^T$$

A - operator of rotation about the following three angles:

- α - angle between the camera axes and normal to the vertical plane of the stay rope
- ω - angle of camera axis inclination
- $\varkappa$ - angle of photographs swing.

The values of the angles ω and $\varkappa$ can be obtained by observation of the points of artificial horizon.

The transformed coordinates make it possible to determine the coordinates of the rope points in the coordinate system (the plane coordinates X_1, Z_1 lies in the vertical plane of the base)

$$X_1 = \frac{Y}{y_t}\,x_t$$

$$Z_1 = \frac{Y}{y_t}\,z_t$$

where: Y - the distance from the camera projection center to the plane of rope

After including the integration constants, the equation of a chain curve become:

$$\bar{z} = \frac{k}{2}\left(e^{\frac{\bar{x}}{k}} + e^{\frac{-\bar{x}}{k}}\right) = k \cdot \cosh\left(\frac{\bar{x}}{k}\right)$$

where: $\bar{x}$, $\bar{z}$ - the coordinates in the chain curve coordinate system

The pull forces can be calculated as:

$F_x = k\,q$ horizontal component of the force

$F_z = k\,q.m_o$ vertical component of the force

$F = \sqrt{F_x^2 + F_z^2}$ the resultant force where: q - weight of 1 m of the rape

$$m_o = \left|\sin h \frac{\bar{X}_o}{h}\right|$$

directional coefficient of a tangent to the chain curve at point $\bar{X}_o$, where rope is fixed to the boring tower.

Having the coordinates X_L, Z_L of rope's points, the approximation by chain curve can be done according to formula:

$$Z_L - \beta = \frac{k}{2}\cdot\left(e^{\frac{X_L-\alpha}{k}} + e^{-\frac{X_L-\alpha}{k}}\right)$$

where: k - parameter of the chain curve

α, β- integration constants, the components of a translationvector from the local coordinate systemto the a coordinate system of the chain curve

The values of the chain curve parameters (k,α,β) are, in the case of redundand observations, determined by least square method .

It is recommended, in such a case, to apply one of the method of orthogonalization, because the set of equation is ill conditioned (strong correlation between unknowns).

Comparing the forces calculeted by this method and measured directly by a dynamometer the accuracy of the method can be estimated. For pull forces ranging from 250 kG, the maximal errors were less then 4 kG.

Conclusions

As can be seen from obtained mean errors, the adjusted value of the time paralaxes is determined with accuracy of 1,6 μm.

Taking into account, that photographs were measured on Stecometer, the results were burden only by observation error of time parallaxes. In typical field condition it is possible to determine the displacement of points of 43 m hight boring tower with mean error equal to ±1.5 mm.

It is high accuracy: it is difficult to achieve such accuracy using even precise surveying methods.

In opinion of a specialist-drillers the results of such measurements are very usefull for safe work of a drilling rig. The demand for such measurement should rise in future.

The pull forces of stay ropes of boring tower were determined by approximation of chain curve parameter with accuracy of 0,7 - 1,6 %.