About designing the internal layout grid of the main NPP building

M Ya Bryn, Yu V Lobanova*, A A Nikitchin
Emperor Alexander I St. Petersburg state transport university, 9, Moskovskiy avenue, St. Petersburg, 190031, Russia

E-mail: lobanowa@mail.ru

Abstract. When carrying out the construction and installation works of nuclear power facilities, one of the main stages of geodetic work at a construction site is the creation of a layout grid. The article considers the issue of designing an internal layout grid at the source and installation horizons. It is proposed to use the free stationing method when creating the internal layout grid. A model of the internal circuit in the reactor building was created and accuracy pre-calculation was performed.

Improving the quality of construction and installation works of nuclear power facilities can be achieved by a comprehensive implementation of various types of support, primarily geodesic. One of the main stages of geodetic work at a construction site is the creation of a layout grid, which includes a layout grid of a construction site, an external layout grid, an internal layout grid at the initial and installation horizons, as well as a layout grid for the installation of technological equipment, if this is provided for by the geodetic works project (PPGR).

Let's turn to the creation of an internal layout grid. Such a grid is designed to perform detailed alignment work and transfer coordinates to installation horizons. As a rule, it is created in the form of a grid of geodetic points at the initial and installation horizons of the structure, while the internal layout grid of the building (structure) on the initial horizon is linked to the points of the external layout grid, and on the millwright horizon, to the points of the internal layout grid of the datum line [1–5].

In recent years, the need for the design of internal layout grids has arisen, due to constrained and limited visibility conditions, the complex construction of buildings and structures, and, as a result, the complex geometry of the grid; increased requirements for the accuracy of geodetic works; the use of high-precision geodetic instruments in production and the wider use of the stakeout works free stationing method and performing surveys, etc. When designing a grid, the issues of choosing the most rational option for building a grid with different composition of measurements and different locations of the source and determined points, at which the required accuracy is ensured, are the solved determination of equalized grid elements at the lowest cost of labor, money and time for their production.

Let us consider the methodology for designing an internal layout grid using the example of designing a grid for the nuclear power plant main building construction.

The starting points for the design of the internal layout grid are the axial points of the existing external layout grid, the list of coordinates of these points is presented in Table 1.

Table 1. List of starting points’ coordinates

| Coordinate | Value |
|------------|-------|
| X          |       |
| Y          |       |
| Z          |       |
It was planned to fix on the object of work with the reflective films and determine the position of eight points of the internal layout grid M1 - M8 (Figure 2).

To calculate the accuracy of the designed grid, the approximate coordinates of the reflective films were taken from the scheme (Table 2).

![Figure 1. Location of geodetic points](image)

Table 2. The list of coordinates of the internal layout grid’s designed points

| No. | Name | x, m  | y, m   |
|-----|------|-------|--------|
| 1   | M1   | 1804  | 1392.5 |
| 2   | M2   | 1858  | 1433   |
| 3   | M3   | 1858  | 1480   |
| 4   | M4   | 1816  | 1515.5 |
| 5   | M5   | 1773  | 1515.5 |
| 6   | M6   | 1731  | 1480   |
| 7   | M7   | 1697  | 1433   |
| 8   | M8   | 1750  | 1392.5 |

The points coordinates’ determination of the internal layout grid was designed by an electronic total station using the free stationing method from the standing points of the electronic total station (T1, T2, T3, T4). At each standing point of the total station, directions and distances are designed to be carried out at all the starting points and the designated points of the layout grid. In this case, the measurements at the starting points are used to determine the position of total stations, and measurements on grades are used to determine the grades’ position. The advantage of this proposal is that the measurements made will create a reliable grid that repeatedly connects the starting points, the determined points and the standing points of total stations. In this case, there will be no centering errors in the measurement results.
Based on the approximate coordinates of the standing points of the total stations, grades and starting points, horizontal directions and distances are calculated based on the inverse geodesic problem solution, which are a measurement model that should be measured in the designed grid. The calculation results are given below.

The table with the name Tah1 combines the model of measurement results with a total station at point T1, Tah2 - at point T2, Tah3 - at point T3, Tah4 - at point T4. In column 1 of each table, the items’ names are included, in columns 2, 3, 4 - degrees, minutes and seconds of horizontal directions, in column 5 - horizontal distances in m.

\[
\begin{align*}
\text{Tah1} &= \quad \text{Tah2} &= \\
\text{Tah3} &= \quad \text{Tah4} &= 
\end{align*}
\]

The quadratic mean errors of the values expected to be measured should be assigned to determine the measurement results’ scales.

In the general case, the scale of each directly measured quantity is calculated by the formula

\[
p = \frac{c}{m^2},
\]

where \( c \) – is the constant for the grid equal to the squared mean square error of a unit of weight \( \mu \).

Because horizontal directions at grid points are measured equally, it is advisable to take \( \mu = m_N \), where \( m_N \) - is quadratic mean error of horizontal direction measurement.
Then the weights of the horizontal directions and distances planned for measuring the designed grid are calculated using the formulas

\[ p_N = m^2_N / m^2_N = 1; \quad p_S = m^2_S / m^2_S. \]

The quadratic mean error of the direction measurement is \( m_N = m_\beta / \sqrt{2} \), where \( m_\beta \) – defines a quadratic mean error.

The quadratic mean error of distance measurement by electronic total stations should be assigned based on the rating characteristics of these devices.

For example, if the quadratic mean error of measuring the sides length by an electronic total station is 2 mm +2 mm / km, then provided that each line is measured twice (straight and back), the error of the two measurements average will be 1.4 mm + 1.4 mm / km.

If it is assumed that satellite measurements will be performed in the grid, then the quadratic mean error of determining the increments of the planned coordinates should be taken as 5 mm +1.5 mm / km.

If, when evaluating the projects, a transition from rectangular to polar coordinates is required, this will mean that the quadratic mean error in the vector length is 5 mm + 1.5 mm / km, and the quadratic mean error (sec) in its direction is \( \frac{5 + 1.5D}{D10^6} \), where \( D \) is expressed in km.

With independent measurements of the weight, the measurement results can be combined into a diagonal matrix of weights

\[
P = \begin{bmatrix}
p_1 & 0 & \ldots & 0 \\
0 & p_2 & \ldots & 0 \\
\ldots & \ldots & \ldots & \ldots \\
0 & 0 & \ldots & p_n
\end{bmatrix}.
\]

Finding the quadratic mean error of the estimated values is carried out according to the algorithm of the parametric method. Amendment equations are compiled [6 - 8]. To determine the inverse weight matrix, it is necessary to compose the corresponding correction equations for all “measured” quantities. In the matrix form, the equations of corrections with the parametric method of adjustment will be:

\[ B\delta x + L = V, \]

where \( B \) – is the coefficient matrix of corrections equations; \( \delta x \) - is the vector of unknowns, i.e., the corrections to approximate parameter values, \( L \)- is a free member vector, \( V \)- is the vector of corrections to the measurement results. At the design stage, the vector of free members \( L \) will be absent. The matrix of normal equations coefficients will be \( N = B^T PB \). At \( n \) “measured” quantities and \( k \) independent parameters matrix \( B \) has the size \( n \times k \), the coefficient matrix \( N \) has the size \( k \times k \). By performing a matrix inversion on a personal computer \( N \), the matrix \( Q_{\delta x} = N^{-1} = (B^T PB)^{-1} \) can be found, which will be the inverse weight matrix of the adjusted coordinates of the points. The inverse weight matrix of the equalized measured values will be \( Q_{\beta,5} = B(B^T PB)^{-1} B^T \).

The diagonal elements of the inverse weight matrix are the inverse weights. Using them and setting the a priori value of the quadratic mean error of a unit of weight, it is possible to determine the quadratic mean errors of the equalized grid elements using

\[ m = \mu_0 \frac{1}{\sqrt{p}}. \]

Calculation of the designed grid accuracy was carried out according to Professor Kougia V.A., developed at the Department of Engineering Geodesy of St. Petersburg University of Railway Engineering [6] by means of NW computer program. When calculating the accuracy, the starting points coordinates are accepted as error-free. The quadratic mean errors of measurements by an electronic total
station are taken equal: for the directions - 2, for the distances - 2 mm. Below is the result of processing the measurement results using the computer program.

Checklist of calculated coordinate points.

| No. | Name | x     | y     |
|-----|------|-------|-------|
| 1   | D2   | 1800.000 | 1299.992 | initial |
| 2   | D3   | 1800.000 | 1682.373 | initial |
| 3   | 74   | 1657.526 | 1474.987 | initial |
| 4   | 72   | 2130.000 | 1475.017 | initial |
| 5   | M1   | 1804.000 | 1392.500 |
| 6   | M2   | 1858.000 | 1433.000 |
| 7   | M3   | 1858.000 | 1480.000 |
| 8   | M4   | 1816.000 | 1515.500 |
| 9   | M5   | 1773.000 | 1515.500 |
| 10  | M6   | 1731.000 | 1480.000 |
| 11  | M7   | 1697.000 | 1433.000 |
| 12  | M8   | 1750.000 | 1392.500 |
| 13  | T1   | 1804.000 | 1433.000 |
| 14  | T2   | 1820.000 | 1480.000 |
| 15  | T3   | 1773.000 | 1480.000 |
| 16  | T4   | 1750.000 | 1433.000 |

Information about the accuracy of the grid elements:

The weakest point of the grid: M7
m_x = 1 mm; m_y = 1 mm; M = 1 mm;
ellipse of errors: m_{max} = 1 mm; m_{min} = 1 mm;
large direction: 6.6°.
The weakest grid side: M3–T2
quadratic mean error along the side: 1 mm;
quadratic mean error: 0 mm;
relative error in the side length: 1/42700
quadratic mean error in differential angle: 1.9 sec
The accuracy characteristics are calculated by using the values of the quadratic mean errors specified by the user.

Summary
As a result of the calculations, it was shown that the quadratic mean errors of determining the coordinates of all points of the grid do not exceed 1 mm. The weakest point of the grid was point M7. The quadratic mean errors of its coordinates, rounded to the nearest millimeter, are equal to: m_x = 1 mm, m_y = 1 mm and M = \sqrt{m_x^2 + m_y^2} = 1 mm. The accuracy of the weakest side of the M3 – T2 grid 38 m long is characterized by the quadratic mean errors: along the sides - 1 mm, across the side - 0 mm, relative error in the length of the side 1: 42700 and quadratic mean direction error 1.9.

The pre-calculation shows that the proposed methodology for creating an internal grid, associated with low labor costs and execution ease, leads to the creation of a high-precision grid by using the free stationing method. According to the authors, such a pre-calculation should always be carried out in the project for the geodetic works production development.

References
[1] Sytnik V S, Klyushin A B, Borisenkov B G 1982 Geodetic support of construction and installation works (Stroyizdat, Moscow) 159.

[2] Zhukov B N, Karpik A P 2006 Geodetic control of engineering facilities of industrial enterprises and civil complexes (Novosibirsk, SSGA) 148.

[3] Levchuk G P, Novak V E, Konusov V G 1981 Applied geodesy: Basic methods and principles of engineering and geodetic work: Textbook for universities (Nedra, Moscow) 438.

[4] Charter G A, Kostina G D 1983 Geodetic works during the construction and operation of large energy facilities (Nedra, Moscow) 133.

[5] SP 126.13330.2017 Geodetic works in construction, Ministry of Construction of Russia, Moscow, GP CPP, 2017, 73.

[6] Gerasimov A P 1996 Equalization of the state geodetic grid (Kartgeotsentr - Geodezizdat, Moscow) 216.

[7] Kougia V A 2012 Selected Works: Monograph (Spb., PGUPS) 448.

[8] Mashimov M M 1989 Leveling of geodetic grids. - 2nd ed., Revised. and add (Nedra, Moscow) 280.