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ORIENTATION TO BASELINES FOR BUILDING SITE NETWORK

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Abstract. Design engineers prefer working with actual ground distances. Therefore, the points of building site network should have the coordinates of the national grid system and the independent site grid system ("flat Earth"). The site network is usually formed and adjusted as a closed loop traverse (or triangulateration braced quadrilaterals or polygons with a central point) that commences from the first point with a direction angle of the baseline. These conditions cause some special requirements and methods of traverse adjustment and orientation (or other type of a network). This study determines the allowed deviation of baseline orientation from its ideal values of a typical building site network.

Keywords: surveying with construction applications, setting out technology, building site network, adjustment.

1. Introduction

Relatively high accuracy is needed for setting out and as-built surveys in the construction sites. Regrettably, the internal accuracy of national geodetic control points may often be insufficient for some construction works. In addition, as is well known, one of the basic requirements for building site network is that reductions in a geodetic reference ellipsoid and due to map projections (for example, effects could be relatively large and reduction in the line of 200 m on the central meridian of TM projection equals 80 mm) should be avoided in the majority of cases. This is due to the fact that design engineers customarily work with actual ground distances. There is also a need for linking a building site to national or regional infrastructure objects such as pipelines, motorways and railways and power transmission lines; hence, it is requested to calculate building site network with respect to the national coordinate system (Левчук 1970; Smith 1997).

Therefore, building site network is connected to the national geodetic network with reference to the obtained traverse measurements or GPS. The length of the traverse could reach as much as a few km. The adjustment of connecting such a traverse is executed in the usual manner. Let us review a simple typical case where APQL is connection traverse and PQMK is building site network (see Fig. 1) with an emphasis on the problems of adjustment and orientation to building site network.

2. The Essence of the Problem

The coordinates of the national network (points A and L in Fig. 1) are held fixed, whereas all necessary reductions due to map projection will be considered. Let us assume that connecting traverse passes via points P and Q that form a baseline (with direction angle α_{PQ}) for controlling a network on the building site (see Fig. 1).

Next, after measuring the distances and angles of the closed loop traverse PQMK, the coordinates of building site network (in addition to P and Q, also K and M, see Fig. 1) are to be computed. By fixing the national coordinates of P and Q and applying all necessary reductions, we obtain the national coordinates of points M and K. However, we also need the coordinates of PQMK in the grid system of the site.
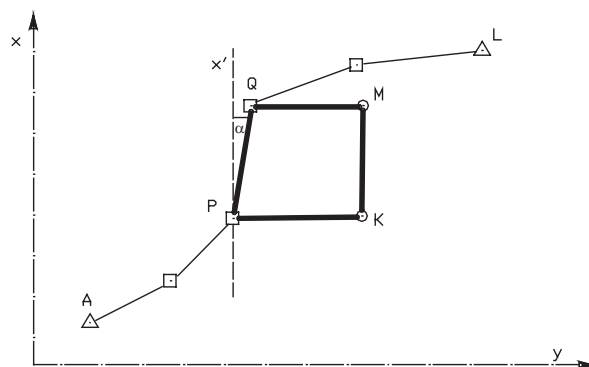

Fig. 1. Connecting traverse and building site network

The following two grid systems of the site may be considered:
  – a parallel system, when the coordinate axes of the site grid are parallel to the coordinate axes of the national system (see Fig. 1);
  – a non-parallel system, when the coordinate axes of the site grid are twisted with respect to the co-ordinate axes of the national system. The origin of the system is usually placed to the immediate neighbourhood of the building site so that the whole site would be located in the first quadrant, see Fig. 3.

Let us examine a more simple first case, see Fig. 1. The national coordinates of point P and the initial direction angle α_{PQ} in the national system (from connecting traverse adjustment) are taken as origin. No reductions in the ellipsoid and map projection to PQMK sides are used and the coordinates of points Q, M, K will be computed in the system of the site network. Certainly, due to used initial data and adopted assumptions, the coordinates in the system of the site network are expected to be close (but not the same!) to those of the national system.

Next, we focus on the case when baseline PQ is either close to the north-south direction (see Fig. 1) or the east-west direction. **We suggest that in such a case only one Q coordinate – either x_Q or y_Q will be adjusted.** If $\alpha_{PQ} \approx 0^o$ (or 180°), then preferably only x_Q will be adjusted and y_Q is to be held fixed, because **adjusting y_Q changes predominantly α_{PQ} value as well.**

Actually, adjusting x_Q also changes α_{PQ}, though it is generally to a lesser degree. The more α_{PQ} differs from 0° (or 180°), the more altering x_Q changes α_{PQ} (see Fig. 2). A similar effect takes place if α_{PQ} is about 90° or 270°; then, adjusting y_Q is only needed. However, **a precondition that the initial direction angle for every geodetic system must remain constant is necessary.**

This contribution attempts to find the most optimum solution for such a case.

In this case, a problem arises. How much x_Q can be altered for changes in α_{PQ} to remain insignificant?
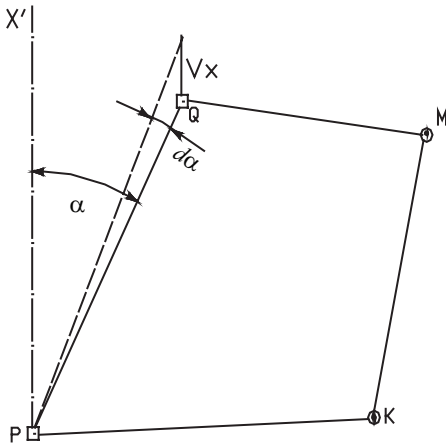

Fig. 2. Adjustment correction v_x of point Q brings about the change $d\alpha$ of the initial direction angle α_{PQ}. Axis x' is parallel to x coordinate axis

3. Recommendations for Orientation to Baselines for Building Site Network

A differential equation of direction angles (Селиханович 1981) can be applied to find the permitted value of α_{PQ}, i.e. permitted deviation from NS or EW direction

$$d\alpha = \frac{-\rho\sin\alpha\times dx}{s} + \frac{\rho\cos\alpha\times dy}{s}, \qquad (1)$$

where $d\alpha$ – permitted change in the baseline direction angle due to change in the coordinates of baseline endpoint (Q); s – the length of the network side; α – a direction angle of the network baseline; dx, dy – are the components of misclosure.

As we do not adjust to y_Q (i.e. $dy = 0$), there is no need to account for the second term of Eq. (1), and thus we have the absolute value:

$$d\alpha_{PQ(perm)} = \arcsin\frac{d\alpha\times s}{\rho\times dx}. \qquad (2)$$

Assuming:
  – that the total station to be used has the nominal distance measurement accuracy of 2 mm + 2 ppm and the accuracy of angle measurements (by DIN 18723, 2002) is 1";
  – distances PK, KM, MQ, QP are about 200 m and the form of quadrangle PKMQ is near a quadrate; then the program Local X•Positioning System gives the mean square error (MSE) of y_Q as 5.2 mm and $v_x = dx = 2.5 \times 5.2 = 13$ mm.

Further, for adopting a permissible change in baseline direction angle $d\alpha = 0.5$" (in this case, the initial direction angle practically remains unchanged), we can find the maximum value of the deviation of baseline direction angle from NS or EW direction for site network (see Section 2)

$$\alpha_{PQ(perm)} = \arcsin\frac{0.5\times 200000}{206265\times 13} = 2.14^{\circ}, \qquad (3)$$

i.e. $0^{\circ} \pm 2.14^{\circ}$, (or $90^{\circ} \pm 2.14^{\circ}$ or $180^{\circ} \pm 2.14^{\circ}$ or $270^{\circ} \pm 2.14^{\circ}$). This sets rather strict requirements for orientation to baselines for the site network.

If the required accuracy of building site network is lower/higher, the network described in this section (i.e. the predicted misclosure $v_x = dx$ (or $v_y = dy$) is larger/smaller than 13 mm and/or sides are shorter/longer than 200 and $\alpha_{PQ(perm)}$ value changes approximately proportionally to

$$\frac{d\alpha''}{dx_{mm}} \text{ and } \frac{s_m}{200}, \qquad (4)$$

where s_m – the average length of the sides (m); dx_{mm} is predicted v_{xQ} (mm).
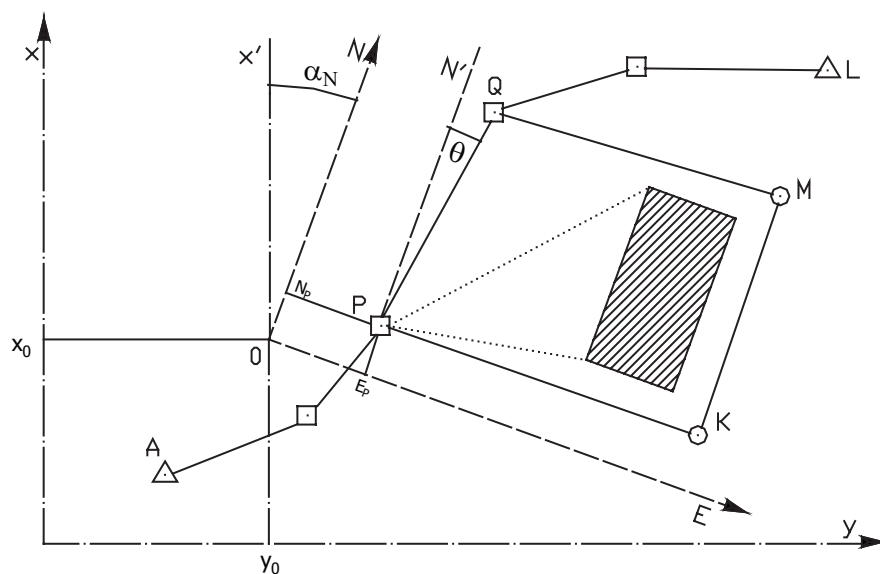
Fig. 3. Connecting building site network by means of a connecting traverse in case
it is used as a non-parallel site grid coordinate system (N, E)

4. Features of Orientation to Baselines for the Non-Parallel Reference System

In this section, we briefly deal with the second case – a non parallel reference system, such as a location grid, site grid or structural grid (ISO 4463-1), the coordinate axes of which are parallel to the axes of the main constructions (Fig. 3).

The most important benefit of such non-parallel reference system is that orientation to the baseline for building site network close to the direction of the site grid axis is in many cases more convenient than using a baseline with direction close to the coordinate axis of the national coordinate system.

Second, the parallelism of the coordinate axes of the site grid and main constructions simplify significantly the works of design engineers and surveyors.

Third, the coordinates of the numerical values of the arbitrary grid are not similar to that of the national system i.e. an accidental mix between the coordinates of the site grid and that of the national system can be easily avoided. The permitted deviation $\theta_{PQ(perm)}$ of site network baseline PQ from the axis N of the site grid can be found by means of Eq. (5), similar to Eq. (2), by replacing $d\alpha \to d\theta$ and $dx \to dN$.

$$\theta_{PQ(perm)} = \arcsin \frac{d\theta \times s}{\rho \times dN}. \tag{5}$$

5. Summary

One of the basic requirements for processing data on building site network is that reductions in the ellipsoid and map projection should be avoided, because design engineers customarily work with actual ground distances. However, a site network should be connected to the national coordinate system for linking the building

site to regional infrastructure objects. Thus, the points of building site network should have the coordinates of both – national and building site grid systems.

A pair of points usually belongs to connection traverse and is taken as a baseline for the site network. The coordinates of the first point (as origin) and the direction angle of the baseline are obtained immediately from connecting traverse adjustment. When adjusting the site network in the site grid system, no reductions in the ellipsoid and map projection to the sides of the network will be assigned.

Note that the direction angle of the baseline should remain the same, although we use free (more exactly – semi-free) adjustment. Nevertheless, after adjusting the coordinates of the direction point (backsight point) of the baseline, the direction angle may change. Nevertheless, it is a well-known assumption that the initial direction angle of a right geodetic system must be constant.

To minimize this change (to become even insignificant), the direction angle of the baseline should be oriented either to NS or EW direction approximately and use corrections to the second point of baseline only, i.e. v_x or v_y (which is about along the baseline).

If the direction angle is not exactly equal to 0°, 90°, 180° or 270°, the change of one coordinate of the second point of the baseline brings along a slight change in the other coordinate. The permitted range of the change can be found by means of the differential equation of direction angles. This study has demonstrated that the maximum deviation of the direction angle from NS or EW direction should be no more than 2.14° for a precise building site network.

If the required accuracy of the network is lower/higher and the sides are shorter/longer, the maximum deviation of the direction angle will change approximately in proportion to $\dfrac{d\alpha''}{dx_{mm}}$ and $\dfrac{s}{200}$, where $d\alpha''$ is per-

missible change in the direction angle; dx_{mm} – predicted v_x in the units of mm; s – the average side of the site network in the units of m. The corresponding permitted values depend on the features of constructions and should be determined in cooperation with design engineers.

We have also showed that in the case of the non-parallel reference system, the permitted deviation can be found by using the equations of the parallel grid. For instance, the permitted deviation $\theta_{PQ(perm)}$ of the baseline for the site network from the axis N of the site grid can be found by means of Eq. (5), which is similar to Eq. (2).

Acknowledgment

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