Journal of Physics: Conference Series

Validation of the method of height transmission by laser tape measure in construction

Validation of the method of height transmission by laser tape measure in construction

Tran Thanh Son[1], A A Kuzin[1], M G Mustafin[1]

[1] Saint Petersburg Mining University, 2, 21 Line, Saint Petersburg, 199106, Russian Federation

E-mail: kuzin_aa@pers.spmi.ru

Abstract. The article deals with the features of the use of laser tape measure for the transfer of heights from the Earth surface to the upper levels in civil engineering and to a mine in surveying. The most suitable engineering solution for the transfer of height to the mine is justified. Certain experimental results are presented. The algorithm that increases the accuracy of the transmission marks to the mine in the construction of deep tunnels is developed.

1. Introduction

During the construction of high-rise buildings for civil and industrial purposes, tower-type structures (chimneys, silos, cooling towers, etc.), the construction of tunnels and mines, transferring of the high-rise base point coordinates to the installation horizons is needed. The current edition of the SNiP standard on geodetic works in construction [6] recommends solving the problem of transferring the coordinates upward by means of inclined, vertical projection or using GNSS technologies. In fact, it is possible to identify a greater number of ways to solve this problem. In order to ensure maximum efficiency in tunnel construction and within acceptable limits, it is necessary to solve the problem of improving the accuracy of the geodetic framework in the construction of tunnels.

In the construction of mines and tunnels, various methods of transferring height to the tunnel through a vertical well are used to create a geodetic high-altitude network [1–3]. According to the previous research data [4,5], the method of height transmission through a vertical well can be carried out by means of an electronic total station. However, this method has some disadvantages, such as the difficulty of installing a prism reflector at the shaft mouth, impossibility of its orientation and rotation at angles up to 45°, etc. In order to compensate for the disadvantages of this method, it is necessary to study and choose a height transmitting method through a vertical well with a distance measuring device Leica DISTO pro4a. This will improve the accuracy of the orientation of the tunnel and will help to comply with the terms and schedule of the construction of the tunnel in practice.

2. Materials and methods

The principle of height transfer from the ground to the tunnel is the task of two-level surfaces: one is on the ground, the other is in the tunnel. It is possible to transfer the height from the ground to the tunnel if the distance between the two surfaces is known.

The height transmission scheme by the distance measuring device DISTO pro4a and the level through a vertical well into the tunnel is shown in Figure 1.

The laser tape measure Disto (D) is suitable for the use at the shaft mouth, when hanging on a cord about 15 cm long so that the laser beam of the Disto tape measure coincides with a steep line. In the mine, at the projection point of the laser beam, it is necessary to set the prism or reflective paper (O).

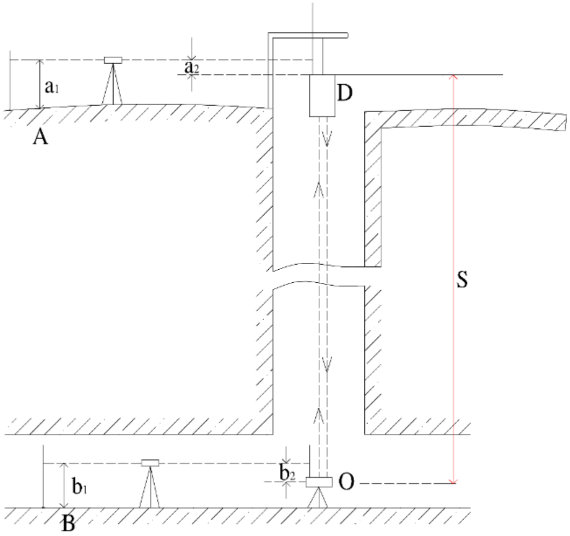

Figure 1. Scheme of height transmission to the tunnel through a vertical well

The order of measurements in the transmission of height from the surface of the earth to the mine is as follows. First, the excess between point A, located on the earth's surface at an altitude of H_A and the installation point of the Disto laser tape is measured. At the point A, the level rail is set and the count in mm (count a_1) is taken; at the point located at the base of the Disto, the count a_2 in mm is taken with a steel ruler with millimetre divisions. The distance S from the base of the Disto to the prism O is then measured. In the mine, it is necessary to measure the excess between the prism O to point B, the height of which must be determined when conducting centre work. At the same time, two counts are taken in the mine: count with the steel ruler located at point B (count b_1), and count b_2 in mm on the steel ruler located on the prism O (number value). Then the height of point B in the tunnel is calculated as follows:

$$H_B = H_A + (a_1 - a_2) - S - (b_1 - b_2), \tag{1}$$

where: H_A is the height of the point A on the surface; a_1, a_2 are the values of the marks on a steel ruler (mm) on the earth's surface; S is the distance from the base of the Disto the device to a prism; a_1, a_2 are the readings in mm on the steel ruler at the mine.

Formula (1) can be written as follows:

$$H_B = H_A + h_1 - h_2 - h_3, \tag{2}$$

where: $h_1 = a_1 - a_2$; $h_2 = S$; $h_3 = b_1 - b_2$.

2.1. Method of accuracy assessment

The formula (2) provides the following:

$$m^2_{H_B} = m^2_{H_A} + m^2_{h_1} + m^2_{h_2} + m^2_{h_3}, \tag{3}$$

where: is the average root-mean-square (RMS) error of the source point (if the RMS error is not considered in the initial point, m_{H_A}= 0); $m_{h_1}$are the RMS errors of measurements during the geometric levelling on the surface of the earth; are RMS errors of laser tape distance measure by Disto; are RMS errors of measurements during the geometric levelling in the mine.

By replacing: $m^2_{h_2} = m^2_S$, on the principle of equal influence [8-9]:

$$m_h = m_0 = m_{a_1} = m_{a_2} = m_{b_1} = m_{b_2} \Rightarrow m^2_{h_1} + m^2_{h_3} = 4m_0^2 \tag{4}$$

By replacing in the same way in the formula (3):

$$m^2_{H_B} = 4m_0^2 + m_S^2 \Rightarrow m_{H_B} = \sqrt{4m_h^2 + m_S^2}\,. \tag{5}$$

Thus, the accuracy of this method depends on the accuracy of the measurement of height difference on the surface of the earth, as well as in the mine (m_h) and the accuracy of the distance measuring device Disto (m_S). According to the manufacturer's specification, the Leica DISTO pro4a has a distance measurement accuracy of $m_S = \pm$ 1.5 mm. If the RMS error is the measurement of the excess equal to m_h = 1 mm, then $\mathrm{m_{H_B}}$ = 4.3 mm. However, experiments are needed to verify the RMS error value.

When the DISTO laser beam deviates from the vertical line, the difference between the measured distance (D) and the distance measured by the vertical line (S) occurs. Bringing measurements to a vertical line is calculated as:

$$\mathrm{S} = \sqrt{\mathrm{D}^2 - \mathrm{e}^2}\ , \tag{6}$$

where: D is the measurement distance of Disto; $\mathrm{e} = \frac{\beta''\mathrm{D}}{\rho}$.

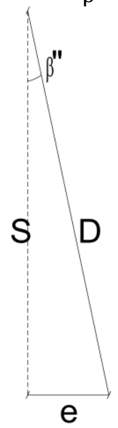

Figure 2. Difference between the distances

When using laser tape measure Leica DISTO pro4a with accuracy $m_S = \pm$ 1.5 mm + 0.03 mm/m, located on the measuring stand at the well to measure at a depth of 100 m, e = 40 cm, the distance difference ($D - S$) is 2.4 mm.

Obviously, the method of height transmission to the tunnel by Disto has many advantages over traditional methods (steel wire or level), but it is necessary to carry out experimental measurements to confirm the accuracy and the possibility of wide method application.

2.2. Experimental computation

Experimental research of the mark transfer technology using laser tape DISTO™ pro4a was carried out by the Vietnam Institute for Building Science and Technology, Ministry of Construction – IBST. The test distance – horizontal distance (measured three times) were simulated. The average value is used, the tension of the steel ruler when measuring is provided by a weight of 5 kg. When using a steel ruler for measurement, it is necessary to calculate the elongation factor of the steel ruler and calculate it according to the measurement results. The elongation factor of the steel ruler is calculated by the formula:

$$\Delta\mathrm{L} = \frac{\mathrm{FL}}{\mathrm{EA}} \tag{7}$$

where: ΔL is the elongation factor of the steel ruler; F is the tension of a ruler by weights when measured (change of 0.1 kg = 9.81 N, i.e. 5 kg = 49.05 N); L is the ruler length (m); E is the modulus of elasticity of steel, E = 2.1 * 105 MPa; A is the width and thickness of a steel ruler (width of 10 mm; thickness of 0.5 mm).

For the length of 10 m it is: ΔL = (9.81 * 5 * 10000) / (2.1 * 105 * 10 * 0.5) = 0.467 mm; the factor is calculated for the lengths of 20 m; 30 m or more multiplied by the ratio. The results of the calculations are presented in Table 1.

Table 1. Calculation results

No.	Steel ruler distance with a tension of 5 kg at the test site (m)	ΔL	Steel ruler distance after correction (mm)	Distance with DISTO pro4a (m)	Difference (mm)
(1)	(2)	(3)	(4) = (2) + (3)	(5)	(6) = (5) - (4)
1	40.000	1.8	40.0018	40.001	- 0.8
2	50.000	2.3	50.0023	50.002	-0.3
3	60.000	2.8	60.0028	60.002	- 0.8
4	70.000	3.2	70.0032	70.002	- 1.2
5	80.000	3.7	80.0037	80.004	+ 0.3
6	90.000	4.2	90.0042	90.006	+ 1.8

Table 1 shows that it is possible to use the DISTO pro4a device to transmit the height to the tunnel through a vertical well at a depth of up to 90 m when the maximum error in the height transmission to the tunnel is ≤ 3 mm [6].

Experimental work was carried out using Leica DISTO™ Pro4a with an accuracy of m_S = ± 1.5 mm+0.03 mm/m. The measurement is performed in accordance with the scheme shown in Fig. 1 (building block N01, 136 Ho Tung Mau, Hanoi, Vietnam). The experiment procedure is shown in Fig. 3.

Figure 3. Experiment in blocks N01, 136 Ho Tung Mau, Hanoi, Vietnam

The Disto was placed in block N01 on the 16th, 25th and 32nd floors. After turning on the laser beam roulette, it is necessary to note the point (O) and to install there a prism or reflective film. The point (O) was located on the second floor. Accordingly, three distances were measured: from the 16th, 25th and 32nd floors to the 2nd floor. Then the height difference was measured by levelling: h_1 and h_3 (from the formula (2)). The results of the calculations are presented in Table 2.

The height transfer to the tunnel through a vertical well was also performed using a steel tape measure in the place where the experimental measurement was carried out by the Disto device. As a result, the height of point B on the second floor by measuring with a steel ruler (with tension by the weight of 5 kg) with a level is shown in Table 3.

Table 2. Experimental measurement results

	Nominal height (H_A) of the floor	Height difference between the reference point A and the device base (stand) ($a_1 - a_2$)	Distance from the Disto device to the film reflector (S)	Height difference between the film reflector and the benchmark B ($b_1 - b_2$)	Height of the benchmark B (H_B) on the 2nd floor
16th floor	0.000	0.328	45.139	– 0.126	– 44.685
25th floor	0.000	0.316.	73.953	– 0.126	– 73.511
32nd floor	0.000	0.322	96.340	– 0.126	– 95.892

Table 3. Comparison of the results of height transmission by two methods

	Height of the benchmark B by the steel ruler (m)	ΔL (mm)	Steel ruler distance after correction (mm)	Distance with DISTO pro4a (m)	Difference (mm)
(1)	(2)	(3)	(4) = (2) + (3)	(5)	(6) = (5) - (4)
16th floor	– 44.683	– 2.1	– 44.6851	– 44.685	– 0.1
25th floor	– 73.508	– 3.4	– 73.5114	– 73.511	– 0.4
32nd floor	– 95.886	– 4.5	– 95.8905	– 95.892	– 1.5

Comparison of Tables 2 and 3 shows that the height measured by the DISTO pro4a compared with the height measured by the traditional method has the results of deviations within the permissible limits (3 mm) at a depth of 95 m. This error meets the standard of height transmission in Russia [6] and Vietnam [7]. The experimental results show that it is possible to use the Disto device to transmit the height to the tunnel through a vertical well up to 95 m in depth to overcome the general technical difficulties when using other methods to transmit the height to the tunnel.

3. Conclusion

According to the results of theoretical and experimental analysis, the following conclusions can be drawn.

1) The use of the Disto device with the standard deviation up to m_S = 1.5 mm + 0.03 mm/m for height transmission through the vertical well of the tunnel is particularly effective when the tunnel depth is up to 95 m. Further research is needed when the depth of the vertical well exceeds 95 m.
2) For best results, place the Disto device on a vertical well so that the laser is aligned with the vertical line. Then the distance measurement between the Disto device and the reflector reaches the required accuracy.
3) Currently, laser roulette is widely available on the market. For example, Leica Disto D5 or Leica DISTO S910 with an accuracy of m_S = 1.0 mm + 0.025 mm/ m at a distance of 200 m and 300 m, respectively, will also provide the necessary accuracy of the transmission of marks to the depth of 95 m. The use of these roulettes for height transmission to the entire specified range of distance measurement should be further investigated.

References

[1]. Pisarenko V K, Shmelin N A Izmaylov R B 2014 Height transmission to the mounting horizons *Geodesy and cartography* **10** 2-4.

[2]. Klyushin E B, Gayrabekov I G, Markelova E Yu, Shlapak V V 2015 *Satellite measurement methods in geodesy* (Publishing house of the Moscow State University of Geodesy and Cartography).
[3]. Bogomolova E S et al 2013 Geodesic support of construction of cable-stayed bridges in the city Vladivostok *Journal of Mining Institute* **204** 33-36.
[4]. Tran Viet Tuan 2010 The improving research of method that carry elevation from the earth's surface into the tunel through vertical well by total stations *Journal of Mining and Earth Sciences* **44** 62 – 65.
[5]. Nguyen Quang Thang, Diem Cong Huy 2017 Some solutions to improve the efficiency of application of GPS technology in the construction of high-rise buildings and industrial works *Journal of Construction Science* **1**. 63–69.
[6]. SP 126.13330.2017. SNiP 3.01.03-84. Set of rules. Geodetic works in construction / The order of the Ministry of Construction of Russia, October 24, 2017 No. 1469. Moscow Ministry of Construction of Russia, 2017. 67 p.
[7]. Van Hien Phan, Viet Tuan Tran, Doan Mau Pham, Xuan Vinh Dinh 2013 Giao trinh Trac dia cong trinh ngam (Hanoi University of Natural Resources and Environment)
[8]. Mustafin M G, Tran Thanh Son 2018 Method of determination of normal heights according to satellite definitions taking into account deviations of a steep line *Geodesy and cartography*. 79(7) 2-10.
[9]. Kuzin A A, Kazantsev A I, Valkov V A 2018 Satellite-based techniques for monitoring of bridge deformations *Journal of Physics: Conference Series* **1118**(1) 1 - 6.
[10]. Kazantsev A I , Kochneva A.A. 2017 Justifcation of quality estimation method of creation of digital elevation models according to the data of airborne laser scanning when designing the motor ways *Journal of Industrial Pollution Control* **23**(2) 1000-1006
[11]. Kuzin A A, Kovshov S.V. 2017 Accuracy evaluation of terrain digital models for landslide slopes based on aerial laser scanning results *Ecology, Environment and Conservation* **23**(2) 908-914.
[12]. V. A. Belin, A.N. Kholodilov, A. P. Gospodarikov 2017 Methodical principles of prediction of seismic effect due to large-scale blasting *Gornyi Zhurnal* **2** 66-70
[13]. E.A. Pravdina, O.J. Lepikhina 2017 Laser scanner data capture time management ARPN Journal of Engineering and Applied Sciences **12** (5) 1649-1661