The Improvement and application of elevation measurement method with total station

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Abstract. In this paper, by analyzing the limitations of the traditional trigonometric elevation method, and on the basis of establishing a mathematical model of trigonometric elevation, a convenient and fast trigonometric elevation method without instrument height and prism height is improved, and the operation steps of the method are introduced in detail. The accuracy analysis was evaluated and the method was applied to actual engineering. The results show that under the premise of ensuring the measurement accuracy, this method not only reduces the range of measurement error sources, but also improves the measurement efficiency.

1 Introduction

In the process of elevation survey or vertical displacement monitoring, due to the low accuracy of trigonometric leveling, people used conventional measuring instruments and leveling methods in road elevation survey or linear engineering monitoring. The total station had been widely used in engineering measurement and engineering monitoring. The total station integrated electronic theodolite, electro-optical distance measurement and data recording, which made its ranging and angle measuring accuracy greatly improved and had the possibility to use it into road elevation measurement. At the same time, the total station had the advantages of fast speed and high efficiency, and it could meet different accuracy of road elevation measurements with different observation methods.

The two methods of leveling and trigonometric leveling in elevation survey had their own characteristics, but both of them still had shortcomings. Leveling is a method of direct height measurement. The accuracy of elevation difference measurement was high, but it was greatly affected by the terrain fluctuation. In addition, the field work was heavy and the work efficiency was low. Trigonometric leveling was a method of indirect height measurement. Although it was not affected by terrain fluctuation and was widely used in large-scale surveying and mapping and linear engineering, its accuracy was low. In the process of measurement each time, the instrument height and prism height must be measured. The process was complex and involves a lot of instrument data, which increased the source of error [1].

The method of trigonometric leveling was improved through engineering practice and exploration. It combined the advantages of leveling and trigonometric leveling. It also combined the characteristics of arbitrary setting of leveling in the survey and the height of the prism and the instrument didn't need to be measured. Without the height difference error caused by instrument height and prism height in the trigonometric leveling process, the measurement accuracy got improved. In the coordinate measurement of road engineering, the surveying and mapping technology with the instrument height and prism height can improve the accuracy of engineering monitoring, coordinate measurement and coordinate lofting, it can also make the measurement process more simple, convenient and faster, it was significant to engineering monitoring and measurement.

2 Mathematical model of total station trigonometric leveling

If the control points were in the mountainous area or on the high-rise building, it would be slow and difficult to measure the height of the points by leveling method. In the traditional engineering survey, it usually used the distance and the elevation difference between the two points, which measured by trigonometric leveling principle, to obtain the elevation of the point to be calculated. Because this method had certain error in the process of the instrument height and the prism height were measured. It led to the result of trigonometric leveling accuracy was lower than the level measurement. It was usually only used in low-level elevation control measurement [2].

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$$H_{AB} = S_2 \bullet \sin \alpha_2 - S_1 \bullet \sin \alpha_1 \quad (1)$$

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3 Traditional trigonometric leveling method and accuracy analysis

$$H_{AB} = V + i\tau \quad (2)$$

$$H_B = H_A + D \tan \alpha + i - t + f \quad (3)$$

Because the calculation of elevation difference with the trigonometric leveling method was according to the instrument height and the prism height, it must consider the influence of their error.

$$m_{\Delta h} = \pm \sqrt{(\sin^2 \alpha_1 + \sin^2 \alpha_2) m_s^2 + (s_1 \cos^2 \alpha_1 + s_2 \cos^2 \alpha_2) m \alpha^2 + m_i^2 + m \mu^2} \quad (4)$$

If the total station could be set up at will, liked the level, instead of being set on the known elevation point and didn't have to measure the instrument height or prism height at the same time, used the trigonometric leveling principle to measure the elevation of the point, then the speed of measurement will be increased under the premise of ensuring accuracy.

As shown in Figure 1, as summed that the elevation of point B was known and the elevation of point A was unknown used the total station to measure the elevation of other points to be measured.

$$H_A = H_B - (D \tan \alpha + i + t + f) \quad (5)$$

$$H_A + i - t = H_B - D \tan \alpha = W \quad (6)$$

d. Aimed at the point in question and measure the elevation.

Let m_s was the mean square error of the slope distance between the instrument and the prism, and m_α was the mean square error of the vertical angle. According to the law of error propagation, the mean square error $m_{\Delta h}$ of the elevation difference between points A and B is:

$$m_{\Delta h} = \pm \sqrt{\sum_{i=1}^n (m^2_i + f^2_i)} \quad (7)$$

$$m_{\Delta h} = \pm \sqrt{\sin^2 \alpha_1 m_{s1}^2 + \sin^2 \alpha_2 m_{s2}^2 + s_1 \cos^2 \alpha_1 m_{a1}^2 + s_2 \cos^2 \alpha_2 m_{a2}^2}$$

Equal precision observation is adopted in the measurement, $m_{a1}=m_{a2}=m_a$, $m_{s1}=m_{s2}=m_s$, this method is a method of non measuring instrument height and prism height, so there is no measurement error of instrument height and prism height [4]. Then the mean square error $m_{\Delta h}$ of the elevation difference between points A and B was:

$$m_{\Delta h} = \pm \sqrt{(\sin^2 \alpha_1 + \sin^2 \alpha_2) m_s^2 + (s_1 \cos^2 \alpha_1 + s_2 \cos^2 \alpha_2) m_a^2} \quad (8)$$

The Leica TS 60 total station was adopted in this survey, the angle measuring accuracy was 0.5" and the ranging accuracy is 0.6mm+1pmm*D. Amplify the measurement error according to the mean square error calculation formula of the total station trigonometric leveling, instrument-free and prism-free measurement [5]. Suppose: $m_a=\pm 1''$, $m_s=\pm 1\text{mm}$, brought them into formula (8), and calculated the mean square error, as shown in Table 1 below:

Table 1. Mean square error with total station measurement method without measuring instrument and prism height

Distance(m)	10	30	50	100	300	500	800	1000
Angle(°)	1°	1.30	2.25	2.91	4.11	7.12	9.19	11.63
	2°	1.30	2.25	2.91	4.11	7.12	9.19	11.63
	5°	1.30	2.24	2.90	4.09	7.09	9.16	11.59
	10°	1.30	2.23	2.87	4.06	7.02	9.06	11.46
	30°	1.33	2.07	2.61	3.63	6.21	7.99	10.10
	45°	1.35	1.88	2.28	3.07	5.13	6.58	8.28
	60°	1.38	1.66	1.90	2.39	3.76	4.75	5.94
	65°	1.39	1.59	1.77	2.15	3.27	4.09	5.64

According to the data analysis in the table, when the vertical angle was in the range of 30 ° to 65 ° and the distance was less than or equal to 100m, the measurement accuracy was the highest.

4.3 Engineering Applications

Most of the construction of highway tunnels used the total station trigonometric leveling technology to monitor the tunnel's vault settlement. As shown in figure 2, monitored the elevation of monitor points G1, G2 and G3, due to the complexity of the construction site environment and the big of the tunnel section elevation difference, and required to use the absolute elevation of the absolute coordinates, so it was not good for the construction of compulsory observation platform or using level, the traditional trigonometric leveling method was also not applicable. Therefore, the above-mentioned

trigonometric leveling method without measuring instrument height was adopted.

Fig. 2. Layout of monitoring points

Monitored started on September 1st, 2019 and ended on November 1st, 2019, the monitoring data table 2 took monitoring point G1 as an example. With the impact of engineering construction and earth excavation, the cumulative change time-history curve of point G1 as shown in figure 3.

Table 2. Vault settlement monitoring data

Date	Observation value			Average value (m)	Accumulated deformation (mm/d)	Accumulated deformation (mm)
	I	II	III			
2019/9/1	199.3601	199.3599	199.3603	199.3601	/	0.0
2019/9/2	199.3560	199.3561	199.3562	199.3561	4.0	4.0
2019/9/5	199.3527	199.3525	199.3523	199.3525	3.6	7.6
2019/9/6	199.3485	199.3486	199.3484	199.3485	4.0	11.6
2019/9/7	199.3449	199.3447	199.3451	199.3449	3.6	15.2
2019/9/8	199.3417	199.3418	199.3419	199.3418	3.1	18.3
2019/9/9	199.3409	199.3407	199.3405	199.3407	1.1	19.4
2019/9/10	199.3389	199.3389	199.3389	199.3389	1.8	21.2
2019/9/11	199.3372	199.3371	199.3373	199.3372	1.7	22.9
2019/9/12	199.3351	199.3350	199.3352	199.3351	2.1	25.0
2019/9/13	199.3340	199.3340	199.3337	199.3339	1.2	26.2
2019/9/14	199.3307	199.3308	199.3303	199.3306	3.3	29.5
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Fig. 3. Time history curve of accumulated change of G1 point

5 Conclusions

(1) The measuring method without measuring the height of the instrument and the prism requires that the height of the instrument and prism remain constant. Except for the height of the instrument and the prism was kept constant in the measurement every time, the instrument, prism rod and prism measured before and after were also kept constant. Only in this way can make sure the measuring accuracy of the method.

(2) Compared with the traditional total station trigonometric leveling method, the improved measurement method reduced the measurement of the height of the instrument and the height of the prism, avoided to bring errors, reduced the workload and improved the measurement efficiency.

(3) According to the practical engineering application, as long as the technical index was properly controlled, the measurement method was correct, and the measures were in place, the elevation measurement method proposed in this paper can basically meet the accuracy requirements of tunnel crown settlement monitoring.

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