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Study on Adaptability of Intermediate Ranging Mode High-precision Elevation Surveying of Total Station Instrument

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ABSTRACT. With the emergence of precision total station instrument, it becomes possible to apply total station instrument for high-precision elevation surveying (height measurement). Different from traditional trigonometric leveling method, "total station instrument intermediate ranging mode elevation surveying method" only measures distance without consideration on measuring angle or height of instrument, all of which can greatly improve observation precision. At present, there are two problems in the existing relevant theoretical and practical researches as follows: first, in the discussion on the measurement accuracy achieved by this method, most literatures only present part of analytical data and rarely include more concrete and comprehensive data. Second, there are many discussions about the feasibility analysis on realization of high grade (precision) measurement, but few about how to carry out specific surveying and what should be paid attention to in practice. In view of the above-mentioned problems, this paper conducts analysis and research on the influence of various factors like the precision, side length and vertical angle of instrument on height difference precision in "total station instrument intermediate ranging mode elevation surveying" method and obtains the applicable conditions for using total station instruments with different precisions to accomplish elevation surveying at different grades. This brings tremendous popularization and application value to high-efficient precision elevation surveying in the circumstance of big height difference and long distance.

Keywords: total station instrument, intermediate ranging mode, precision elevation surveying, applicability.

1. Introduction

In elevation control survey, the commonly-used methods mainly include leveling, trigonometric leveling and GPS observation and each of three methods has advantages and disadvantages. High-grade leveling can achieve high precision, but it is

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greatly affected by topographic fluctuation and constrained by low efficiency. GPS observation has been widely used and studied in engineering survey in recent years, but it is difficult to control the precision due to the inconsistency of height system. With the increase of demand for high-grade complex elevation surveying in recent years, more attention has been paid to the total station instrument elevation surveying. Especially with the emergence of high-precision total station instrument, the research on the application of total station instrument for high-precision elevation surveying becomes a hot spot, such as total station "intermediate trigonometric leveling" method (Yuan 2016, Zhang et al. 2006, An 2009, Zhang et al. 2008, Huang 2008). Meanwhile, further studies show that the improved mode of "intermediate method" namely "total station instrument intermediate ranging mode elevation surveying method" has a good value in in-depth research. This method only measures distance without consideration on measuring angle or height of instrument, which obviously differs from traditional trigonometric leveling. So it should belong to a kind of new pattern. There still exist problems worthy of further in-depth studies in the theoretical and practical research achievements of traditional "intermediate method": first, in terms of applicable conditions and influencing factors, more literatures present partial data and put forward the feasibility of this method to achieve a certain grade of leveling precision, but there are scarce data available for further research. Second, there are many feasibility discussions and analysis under the condition of high precision requirement, but few on how to concretely implement it and what should be paid attention to (Cheng et al. 2011, Du and Man 2012, Li et al. 2016, Li 2015, Lu and Huang 2008, Ning and Cui 2008, Zhang and Lan 1992, Wei 2012, Wang et al. 2014, Wang and Fang 2014, Yu 2006). In view of the above-mentioned problems, this paper conducts exhaustive analysis and research on "total station instrument intermediate ranging mode elevation surveying" method and precision so as to obtain more concrete observation and adaptive conditions that can achieve the precisions of leveling at different grades.

2. Total Station Instrument Intermediate Ranging Mode Elevation Surveying Method

Total station instrument intermediate ranging mode elevation surveying method is to place a total station instrument between the known elevation point and the point to be calculated. Through total station "distance measurement" mode, observe the value of "vertical interval" between the front and rear viewing points and then obtain the height difference between the two points. This method can avoid the height measurement of instrument and the repeated height measurement of prism, thus greatly improving measurement precision.

2.1. Measurement Principle

As shown in Figure 1, place the total station instrument into the middle of two observation points, where point A is the known elevation point while point B is the elevation point to be solved.

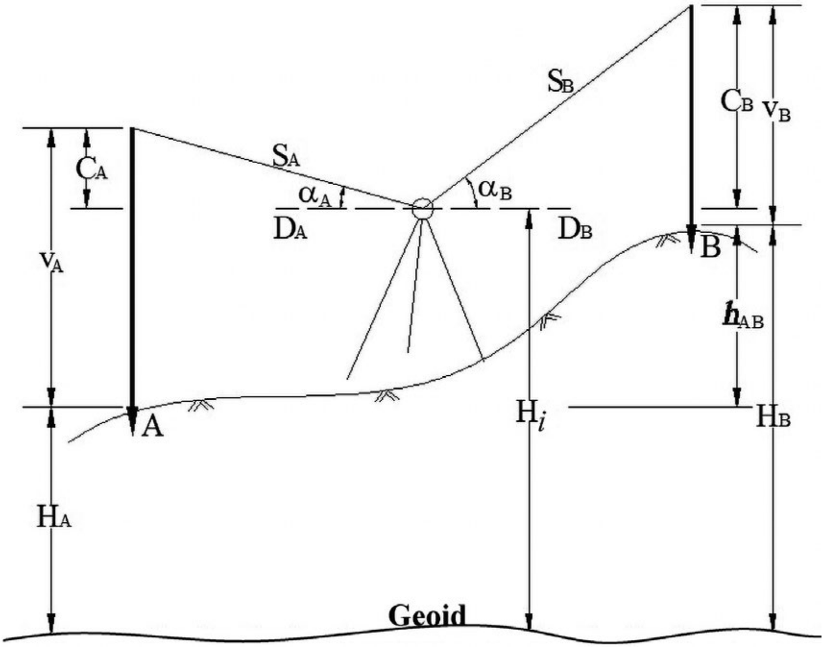

Fig. 1. *The schematic diagram of elevation surveying of total station instrument intermediate method.*

H_A is the elevation value of point A, H_B is the elevation value of point B and H_i is the horizontal axis central elevation value of instrument. And h_{AB} is the height difference value between point A and point B. v_A is the prism height at point A while v_B is the prism height at point B. S_A, D_A, and C_A are respectively the oblique distance, horizontal distance and vertical distance observed at point A. S_B, D_B and C_B are respectively the oblique distance, horizontal distance and vertical distance observed at point B; R is radius of the Earth:

$$H_i = H_A + v_A - C_A + 0.43\frac{D_A^2}{R} = H_B + v_B - C_B + 0.43\frac{D_B^2}{R} \tag{1}$$

$$h_{AB} = H_B - H_A = (v_A - v_B) - (C_A - C_B) + \left(0.43\frac{D_A^2}{R} - 0.43\frac{D_B^2}{R}\right) \tag{2}$$

Assuming $\sum f = 0.43\frac{D_A^2}{R} - 0.43\frac{D_B^2}{R}$. Thus, when $D_A \approx D_B, \sum f \to 0$. That is to say, put the instrument in the middle position of the two points as far as possible (this problem will be specially discussed later). In this case, the calculation formula for the height difference between two points can be simplified as follows:

$$h_{AB} = H_B - H_A = (v_A - v_B) - (C_A - C_B) \tag{3}$$

Here v_A, v_B, C_A and C_B are all observation items. Therefore, on the basis of the above four data observed at each station, we can get the height difference h_{AB} between the known point and the point to be calculated and then the elevation value of the point to be calculated can be obtained according to $H_B = H_A + h_{AB}$.

2.2. Implementation

There is a function in the basic measurement functions of total station instrument, namely "distance measurement" as shown in Figure 2.

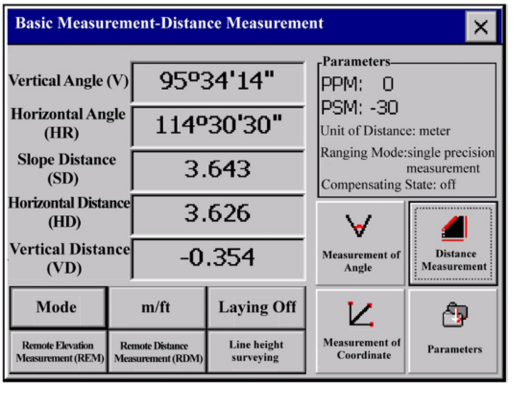

Fig. 2. *Basic measurement functions.*

So the "total station instrument intermediate ranging mode elevation surveying" method mentioned in this paper is realized by this function, which is different from traditional "triangulated height" measurement mode. The following is an example of Southern NTS-370 Total Station Instrument to illustrate the whole surveying process.

(1) Place total station instrument between the two measuring points. Point A is the rear view point while point B is the front view point. Erect center alignment bar of prism vertically at both points, as shown in Figure 3. And set up prism heights v_A and v_B. If possible, make $v_A = v_B$ as far as possible;

(2) Get the instrument leveled after the total station instrument is turned on;

(3) Click the icon "Basic Measurement" on the screen and then Figure 2 appears;

Fig. 3. *Center alignment bar.*

(4) Aim (sight) the center of prism at the rear viewing point A and click "Distance Measurement" button to read HD. Then aim (sight) the center of prism at the front viewing point B and click "Distance Measurement" button to read HD. Enable these two HDs to be equal to each other as far as possible. If unequal, move the total station instrument back and forth and relocate the instrument.

(5) Face left, aim (sight) the center of prism at the rear viewing point A, click "Distance Measurement" button to read VD and make records. That is just C_{AL} in Formula (3). Aim (sight) the center of prism at the front viewing point B, click "Distance Measurement" button to read VD and make records. That is just C_{BL} in Formula (3). The height difference between the two points $h_{\mathrm{ABL}} = H_{\mathrm{B}} - H_{\mathrm{A}} = (v_{\mathrm{A}} - v_{\mathrm{B}}) - (C_{\mathrm{AL}} - C_{\mathrm{BL}})$ can be obtained from Formula (3).

(6) Face right, aim (sight) the center of prism at the rear viewing point A, click "Distance Measurement" button to read VD and make records. That is just C_{AR} in Formula (3). Aim (sight) the center of prism at the front viewing point B, click "Distance Measurement" button to read VD and make records. That is just C_{BR} in Formula (3). The height difference between the two points $h_{\mathrm{ABR}} = H_{\mathrm{B}} - H_{\mathrm{A}} = (v_{\mathrm{A}} - v_{\mathrm{B}}) - (C_{\mathrm{AR}} - C_{\mathrm{BR}})$ can be obtained from Formula (3).

(7) Make the average value of height differences by facing left and facing right be the observed height difference value at survey station 1, namely $h_{\mathrm{AB}} = \frac{1}{2}(h_{\mathrm{ABL}} + h_{\mathrm{ABR}})$.

2.3. Surveying Requirements

2.3.1. Requirements on the horizontal distance between the instrument and these two points

According to Formula (2), the closer the horizontal distance between the instrument to the two points, the closer the two corrections of the effect of Earth curvature and refraction at these two points will be. Thus $\sum f = 0.43\frac{D_{\mathrm{A}}^2}{R} - 0.43\frac{D_{\mathrm{B}}^2}{R}$. The greater the difference between two horizontal distances respectively from the instrument to the two points, the greater $\sum f$ value, and the greater the effect of Earth curvature and refraction will be. Then, what range to be controlled for the difference between horizontal distances of the two points can be considered to have less error influence on observation results and be acceptable? If we take 10% of leveling tolerance at different grades as the maximum value to control the effect of Earth curvature and refraction, thus the dotted line, solid line and dashed line in Table 1 are respectively $\sum f$ value of the difference between different horizontal distances at front viewing point and rear viewing point under the condition of different distances. Here, the dotted line is the boundary for 10% of the first grade leveling tolerance, the solid line is the boundary for 10% of the second grade leveling tolerance, and the dashed line is the boundary for 10% of the third grade leveling tolerance.

Table 1. *The influence of difference between horizontal distances of instrument at front viewing point and at rear viewing point on correction of effect of Earth curvature and refraction Σf (mm).*

The difference between horizontal distances of instrument at front viewing point and at rear viewing point (m)	**The horizontal distance between instrument and measuring point (m)**																
	5	**10**	**20**	**30**	**40**	**50**	**100**	**200**	**300**	**400**	**500**	**1000**	**1500**	**2000**	**3000**	**4000**	**5000**
1	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.04	0.05	0.07	**0.13**	**0.20**	0.27	0.40	0.54	**0.67**
2	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.05	0.08	**0.11**	**0.13**	0.27	0.40	**0.54**	**0.81**	**1.08**	1.35
3	0.00	0.00	0.01	0.01	0.02	0.02	0.04	**0.08**	**0.12**	0.16	0.20	0.40	**0.61**	0.81	1.21	1.62	2.02
4	0.00	0.01	0.01	0.02	0.02	0.03	0.05	0.11	0.16	0.22	0.27	**0.54**	0.81	1.08	1.62	2.16	2.70
5	0.00	0.01	0.01	0.02	0.03	0.03	**0.07**	0.13	0.20	0.27	**0.34**	0.67	1.01	1.35	2.02	2.70	**3.37**
6	0.00	0.01	0.02	0.02	0.03	0.04	0.08	0.16	0.24	**0.32**	0.40	0.81	1.21	1.62	2.43	**3.24**	4.05
7	0.00	0.01	0.02	0.03	0.04	0.05	0.09	0.19	**0.28**	0.38	0.47	0.94	1.42	1.89	**2.83**	3.78	4.72
8	0.01	0.01	0.02	**0.03**	**0.04**	**0.05**	0.11	0.22	0.32	0.43	0.54	1.08	1.62	**2.16**	3.24	4.32	5.40
9	0.01	0.01	**0.02**	0.04	0.05	0.06	0.12	**0.24**	0.36	0.49	0.61	1.21	1.82	2.43	3.64	4.86	6.07
10	0.01	0.01	0.03	0.04	0.05	0.07	**0.13**	0.27	0.40	0.54	0.67	**1.35**	**2.02**	2.70	4.05	5.40	6.75
15	0.01	0.02	0.04	0.06	**0.08**	**0.10**	0.20	0.40	0.61	**0.81**	**1.01**	2.02	3.04	4.05	6.07	8.10	10.12
20	0.01	0.03	**0.05**	**0.08**	0.11	0.13	0.27	0.54	**0.81**	1.08	1.35	2.70	4.05	5.40	8.10	10.80	13.50
25	0.02	0.03	0.07	0.10	0.13	0.17	0.34	**0.67**	1.01	1.35	1.69	3.37	5.06	6.75	10.12	13.50	16.87
30	0.02	0.04	0.08	0.12	0.16	0.20	**0.40**	0.81	1.21	1.62	2.02	4.05	6.07	8.10	12.15	16.20	20.25

Table 2. *10% value of second grade leveling tolerance and third grade leveling tolerance under the condition of different horizontal distances (mm).*

Category	**The Horizontal Distance between Instrument and Measuring Point (m)**															
	10	**20**	**30**	**40**	**50**	**100**	**200**	**300**	**400**	**500**	**1000**	**1500**	**2000**	**3000**	**4000**	**5000**
10% of First Grade Leveling Tolerance	0.03	0.04	0.04	0.05	0.06	0.08	0.11	0.14	0.16	0.18	0.25	0.31	0.36	0.44	0.51	0.57
10% of Second Grade Leveling Tolerance	0.06	0.08	0.10	0.11	0.13	0.18	0.25	0.31	0.36	0.40	0.57	0.69	0.80	0.98	1.13	1.26
10% of Third Grade Leveling Tolerance	0.17	0.24	0.29	0.34	0.38	0.54	0.76	0.93	1.07	1.20	1.70	2.08	2.40	2.94	3.39	3.79

Take second grade leveling precision requirements as an example, when the horizontal distance of side length at front viewing point and at rear viewing point is 500 m, if the total effect of Earth curvature and refraction at Control & Survey Station 1 is less than 10% of second grade leveling tolerance 4 mm (i.e. 0.4 mm, Table 2), the difference between horizontal distances of side length at front viewing point and at rear viewing point shall be less than or equal to 5 m. When the horizontal distance of side length at front viewing point and at rear viewing point is 1,000 m, the difference between horizontal distances of side length at front viewing point and rear viewing point shall be less than 4 m.

2.3.2. Requirements on Difference between Elevation Differences Observed by Plunging Telescope at Survey Station 1

The discrepancy of this elevation difference can be mastered according to the observation requirements on leveling at different grades, as shown in Table 3.

Table 3. *The tolerance of difference between elevation differences observed by plunging telescope at survey station 1 (mm).*

First Grade	Second Grade	Third Grade	Fourth Grade
$1.8\sqrt{K}$	$4\sqrt{K}$	$12\sqrt{K}$	$20\sqrt{K}$

Note: The unit of K is kilometers.

Here K value is the sum of the horizontal distance at front viewing point and the horizontal distance at rear viewing point. Since horizontal distances at front viewing point and at rear viewing point at the time of surveying are basically equal to each other, it can be calculated by 2 times the horizontal distance at front (or rear) viewing point, that is:

$$K = S_A \cdot \cos\alpha_A + S_B \cdot \cos\alpha_B \approx 2S_A \cdot \cos\alpha_A = 2S_B \cdot \cos\alpha_B$$

Table 4. *The tolerance of difference between elevation differences observed by plunging telescope at survey station 1 under the condition of different grade requirements (mm).*

S_A or S_B	First Grade	Second Grade	Third Grade	Fourth Grade
(m)	$1.8\sqrt{K}$	$4\sqrt{K}$	$12\sqrt{K}$	$20\sqrt{K}$
10	0.25	0.57	1.70	2.83
50	0.57	1.26	3.79	6.32
100	0.80	1.79	5.37	8.94
500	1.80	4.00	12.00	20.00
1000	2.55	5.66	16.97	28.28
2000	3.60	8.00	24.00	40.00
3000	4.41	9.80	29.39	48.99
4000	5.09	11.31	33.94	56.57

Note: The unit of K is kilometers.

Under the condition of meeting the requirements on precision at different grades, the allowable value of the difference between elevation difference observed by plunging telescope (face left and face right) at Survey Station 1 of total station instrument can be calculated and it is controlled by the value of tolerance in Table 4.

3. Precision Evaluation

From Formula (3), it can be known that intermediate ranging elevation surveying mode is composed of two semiobservations by plunging the telescope during the surveying process. And the root mean square error (RMSE) of elevation difference in semiobservations is as follows:

$$m_{h_{\mathrm{ABsemi}}}^2 = m_{v_\mathrm{A}}^2 + m_{v_\mathrm{B}}^2 + m_{C_\mathrm{A}}^2 + m_{C_\mathrm{B}}^2 \tag{4}$$

According to the principle of distance measurement of total station instrument, the vertical distance VD (some instruments mark it as elevation difference, which shall be inappropriate) is calculated as $\mathrm{VD} = S \cdot \sin\alpha$. So there are $C_\mathrm{A} = S_\mathrm{A} \cdot \sin\alpha_\mathrm{A}$ and $C_\mathrm{B} = S_\mathrm{B} \cdot \sin\alpha_\mathrm{B}$:

$$m_{C_\mathrm{A}}^2 = \sin^2\alpha_\mathrm{A} \cdot m_{S_\mathrm{A}}^2 + \frac{m_\alpha^2}{\rho^2} \cdot S_\mathrm{A}^2 \cdot \cos^2\alpha_\mathrm{A}$$

$$m_{C_\mathrm{B}}^2 = \sin^2\alpha_\mathrm{B} \cdot m_{S_\mathrm{B}}^2 + \frac{m_\alpha^2}{\rho^2} \cdot S_\mathrm{B}^2 \cdot \cos^2\alpha_\mathrm{B}$$

$$m_{S_\mathrm{A}}^2 = \left(k_1 + k_2 \cdot S_\mathrm{A}\right)^2$$

$$m_{S_\mathrm{B}}^2 = \left(k_1 + k_2 \cdot S_\mathrm{B}\right)^2$$

In the above formulas, k_1 and k_2 are additive constant and multiplication constant respectively.

S_A and S_B are respectively the slope distances between the instrument and the two measuring points, with the unit of m. So we can conclude:

$$m_{h_{\mathrm{ABsemi}}}^2 = m_{v_\mathrm{A}}^2 + m_{v_\mathrm{B}}^2 + \sin^2\alpha_\mathrm{A} \cdot m_{S_\mathrm{A}}^2 + \frac{m_\alpha^2}{\rho^2} \cdot S_\mathrm{A}^2 \cdot \cos^2\alpha_\mathrm{A} + \sin^2\alpha_\mathrm{B} \cdot m_{S_\mathrm{B}}^2 + \frac{m_\alpha^2}{\rho^2} \cdot S_\mathrm{B}^2 \cdot \cos^2\alpha_\mathrm{B}$$

Taking into account that the horizontal distances between the instrument and the two measuring points shall be the same as far as possible during observation, make $D_\mathrm{A} = D_\mathrm{B}$, then $S_\mathrm{A} \cdot \cos\alpha_\mathrm{A} = S_\mathrm{B} \cdot \cos\alpha_\mathrm{B}$, namely

$$S_\mathrm{B} = \frac{\cos\alpha_\mathrm{A}}{\cos\alpha_\mathrm{B}} \cdot S_\mathrm{A}$$

Therefore

$$m_{h_{\mathrm{ABsemi}}}^2 = \left(m_{v_\mathrm{A}}^2 + m_{v_\mathrm{B}}^2\right) + \left(k_1 + k_2 \cdot S_\mathrm{A}\right)^2 \cdot \sin^2\alpha_\mathrm{A} + \left(k_1 + k_2 \cdot \frac{\cos\alpha_\mathrm{A}}{\cos\alpha_\mathrm{B}} \cdot S_\mathrm{A}\right)^2 \sin^2\alpha_\mathrm{B} + \\ + 2\frac{m_\alpha^2}{\rho^2} \cdot S_\mathrm{A}^2 \cdot \cos^2\alpha_\mathrm{A}$$

The prism heights at two measuring points v_A and v_B can be directly read through the scale on center alignment bar, with the same precision. Therefore, make $m_{v_\mathrm{A}} = m_{v_\mathrm{B}} = m_v$, then

$$m_{h_{\mathrm{ABsemi}}}^2 = 2m_v^2 + \left(k_1 + k_2 \cdot \frac{S_\mathrm{A}}{1000}\right)^2 \cdot \sin^2\alpha_\mathrm{A} + \left(k_1 + k_2 \cdot \frac{\cos\alpha_\mathrm{A}}{\cos\alpha_\mathrm{B}} \cdot \frac{S_\mathrm{A}}{1000}\right)^2 \cdot \sin^2\alpha_\mathrm{B} + \\ + 2\frac{m_\alpha^2}{\rho^2} \cdot \left(S_\mathrm{A} \cdot 1000\right)^2 \cdot \cos^2\alpha_\mathrm{A} \tag{5}$$

Formula (5) is the calculation formula for the root mean square error (RMSE) of elevation difference in semiobservations by using intermediate ranging mode elevation surveying of total station instrument.

3.1. Calculation of Root Mean Square Error (RMSE) of Elevation Difference in One-circle Measurement

Suppose the elevation difference in one-circle measurement is h_AB, then there is:

$$h_\mathrm{AB} = \frac{1}{2}\left(h_{\mathrm{AB}_{\mathrm{EarlierSemiobservation}}} + h_{\mathrm{AB}_{\mathrm{LaterSemiobservation}}}\right)$$

Therefore, the root mean square error (RMSE) of height difference in one-circle measurement is: $m_{h_\mathrm{AB}} = \frac{m_{h_{\mathrm{AB}_{\mathrm{Semiobservation}}}}}{\sqrt{2}}$.

Parameters that can bring errors to the observed elevation difference are mainly as follows: error caused by measuring prism height, ranging error (distance-measuring error), vertical angle observation error, the effect of Earth curvature and refraction and so on. Because the horizontal distances observed at the front viewing point and at the rear viewing point shall be equal to each other as far as possible during observation, the effect of Earth curvature and refraction can be ignored.

In calculation, since prism height is generally read from the center alignment bar and tries to keep the same in the observation process, we take $m_v = 1\ \mathrm{mm}$. The ranging error can be calculated by $k_1 + k_2 \cdot \mathrm{ppm}$ (Barković et al. 2016) while angle measuring error can be obtained according to nominal precision of instrument.

3.1.1. Influence of the Vertical Angle Value

Under the condition that the side length remains unchanged and the observed vertical angle values at front viewing point and at rear viewing point change within the whole range of ±80°, the root mean square error (RMSE) of elevation difference in one-circle measurement will increase with the increase of vertical angle. At the same time, the larger the difference between vertical angles at front viewing point and at rear viewing point is, the greater the error will be. The error distribution is saddle-shaped as a whole, as shown in Figure 4.

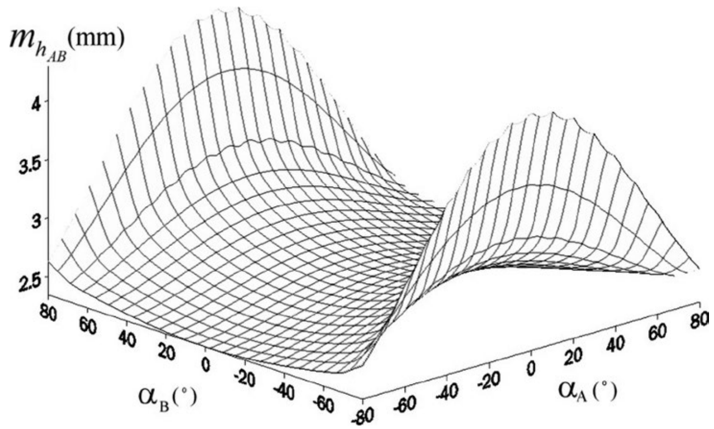

Fig. 4. *Variation of root mean square errors (RMSEs) of elevation difference through total station instrument observation as vertical angle changes.*

3.1.2. Influence of Side Length Values

In the case that the vertical angle is relatively unchanged and the side length changes, to illustrate the problem, we can construct a function to calculate the difference between the root mean square error (RMSE) and allowable error in the elevation difference in one-circle measurement (taking third grade leveling tolerance $12\sqrt{K}$ as an example), namely:

$$f(D) = \left|m_{h_{AB}}\right| - \left|12\sqrt{K}\right|$$

If $f(D) > 0$, it means that it will exceed tolerance requirements. If $f(D) < 0$, it means that tolerance requirement is satisfied. The variation curve of this function with the change of side length is just as shown in Figure 5. This curve shows that root mean square error (RMSE) in the observed elevation difference does not simply increase with the increase of side length. There will be a larger error in the case of relatively short side length and after reaching a certain side length. And the area in the middle can meet the elevation difference requirements.

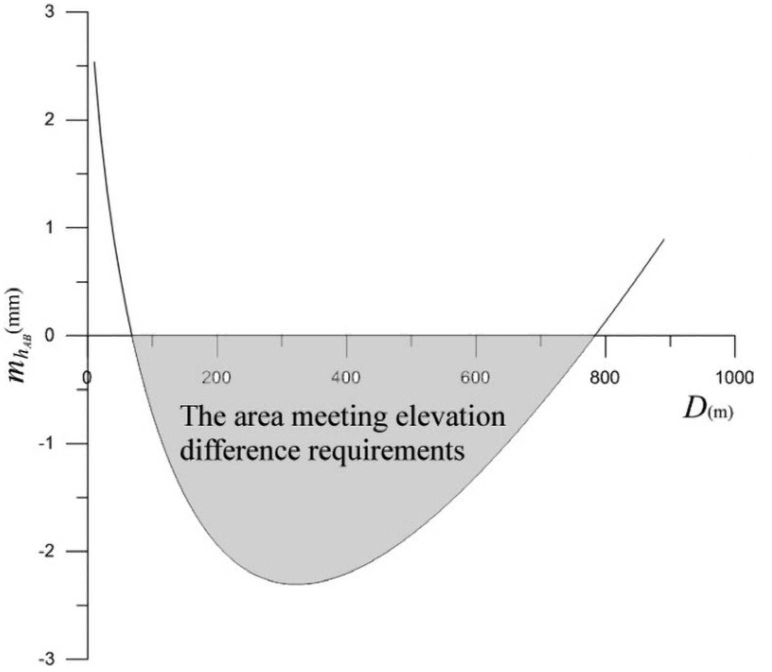

Fig. 5. *Variation of root mean square errors (RMSEs) of elevation difference through total station instrument observation as side length changes.*

3.1.3. Apply 2” Precision Total Station Instrument to Observe Performance of Root Mean Square Errors (RMSEs) in Elevation Difference

Take $m_v = 1$ mm , $m_\alpha = 2''$ and calculate ranging error by 2 mm+2 ppm. With the minimum 5 m as interval, respectively carry out precision analysis and demonstration on the horizontal distance of side length at front viewing point and at the rear viewing point (hereinafter referred to as horizontal distance) such as 5 m, 10 m, 20 m, 30 m, …, 100 m, 200 m, …, 1000 m, …, 2000 m, …, 2800 m, 2900 m, 3000 m, 3100 m, … Table 5 presents data which still do not meet the requirements of third grade leveling tolerance while Table 6 lists the data which can just meet the requirements of third grade leveling tolerance. Along with the increase of horizontal distance, the table does not list the calculation of these increasing horizontal distances that can meet the requirements of this tolerance. Table 7 lists the data that can still meet the requirements of third grade leveling tolerance and Table 8 lists data that start to fail to meet the requirements of third grade leveling tolerance. The shaded area in Table 5–8 shows the data that can meet the requirements of third grade leveling tolerance.

Analysis results show that this precision instrument can meet the requirements of third grade leveling tolerance under the condition of 20 m ≤ horizontal distance ≤ 2800 m and the condition of all vertical angles at front viewing point and at rear viewing point ≤ ±60°. This working condition can satisfy most of large elevation difference observation conditions.

If vertical angle is controlled to be within the range of ≤ ±20°, the horizontal distance can be extended to be within the range of 10 m ≤ horizontal distance ≤ 3000 m.

At the same time, analysis results show that this precision total station instrument cannot meet second grade leveling precision requirements.

Table 5. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 10 m horizontal distance of 2" total station instrument.*

10 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	2.02	1.84	1.66	1.61	1.59	1.61	1.66	1.84	2.02
–40	1.84	1.64	1.44	1.38	1.36	1.38	1.44	1.64	1.84
–20	1.67	1.45	1.22	1.14	1.12	1.14	1.22	1.45	1.67
–10	1.62	1.39	1.14	1.06	1.03	1.06	1.14	1.39	1.62
0	1.60	1.36	1.12	1.03	1.00	1.03	1.12	1.36	1.60
10	1.62	1.39	1.14	1.06	1.03	1.06	1.14	1.39	1.62
20	1.67	1.45	1.22	1.14	1.12	1.14	1.22	1.45	1.67
40	1.84	1.64	1.44	1.38	1.36	1.38	1.44	1.64	1.84
60	2.02	1.84	1.66	1.61	1.59	1.61	1.66	1.84	2.02
Note: $12\sqrt{K} = 1.697$ mm									

Table 6. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 20 m horizontal distance of 2" total station instrument.*

20 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	2.03	1.85	1.68	1.62	1.60	1.62	1.68	1.85	2.03
–40	1.86	1.66	1.46	1.39	1.37	1.39	1.46	1.66	1.86
–20	1.70	1.46	1.23	1.16	1.13	1.16	1.23	1.46	1.70
–10	1.65	1.40	1.16	1.08	1.05	1.08	1.16	1.40	1.65
0	1.63	1.38	1.13	1.05	1.02	1.05	1.13	1.38	1.63
10	1.65	1.40	1.16	1.08	1.05	1.08	1.16	1.40	1.65
20	1.70	1.46	1.23	1.16	1.13	1.16	1.23	1.46	1.70
40	1.86	1.66	1.46	1.39	1.37	1.39	1.46	1.66	1.86
60	2.03	1.85	1.68	1.62	1.60	1.62	1.68	1.85	2.03
Note: $12\sqrt{K} = 2.400$ mm									

Table 7. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 2,800 m horizontal distance of 2” total station instrument.*

2800 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	15.12	14.61	14.44	14.40	14.39	14.40	14.44	14.61	15.12
–40	22.08	21.39	21.17	21.12	21.11	21.12	21.17	21.39	22.08
–20	26.72	25.91	25.66	25.61	25.60	25.61	25.66	25.91	26.72
–10	27.94	27.10	26.84	26.79	26.77	26.79	26.84	27.10	27.94
0	28.34	27.50	27.24	27.18	27.17	27.18	27.24	27.50	28.34
10	27.94	27.10	26.84	26.79	26.77	26.79	26.84	27.10	27.94
20	26.72	25.91	25.66	25.61	25.60	25.61	25.66	25.91	26.72
40	22.08	21.39	21.17	21.12	21.11	21.12	21.17	21.39	22.08
60	15.12	14.61	14.44	14.40	14.39	14.40	14.44	14.61	15.12
Note: $12\sqrt{K} = 28.900$ mm									

Table 8. *Difference root mean square errors (RMSEs) at all vertical angles at 3,000 m horizontal distance of 2” total station instrument.*

3000 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	16.14	15.61	15.43	15.39	15.38	15.39	15.43	15.61	16.14
–40	23.62	22.89	22.66	22.61	22.60	22.61	22.66	22.89	23.62
–20	28.60	27.75	27.49	27.44	27.42	27.44	27.49	27.75	28.60
–10	29.90	29.02	28.75	28.70	28.68	28.70	28.75	29.02	29.90
0	30.34	29.45	29.18	29.12	29.11	29.12	29.18	29.45	30.34
10	29.90	29.02	28.75	28.70	28.68	28.70	28.75	29.02	29.90
20	28.60	27.75	27.49	27.44	27.42	27.44	27.49	27.75	28.60
40	23.62	22.89	22.66	22.61	22.60	22.61	22.66	22.89	23.62
60	16.14	15.61	15.43	15.39	15.38	15.39	15.43	15.61	16.14
Note: $12\sqrt{K} = 29.394$ mm									

3.1.4. Apply 1” Precision Total Station Instrument to Observe Performance of Root Mean Square Errors (RMSEs) in Elevation Difference

Take $m_v = 1$ mm, $m_\alpha = 1''$ and calculate ranging error by 1 mm+1 ppm. The calculation results show that this kind of instrument can meet all third grade leveling precision requirements of observation under the condition of 10 m ≤ horizontal distance ≤ 10000 m and the condition of vertical angle ≤ ±60°. Moreover, this instrument can also meet second grade leveling precision requirements in some cases. The shaded area in Table 9–12 shows the data that can meet the requirements of second grade leveling tolerance. And the conditions for it to meet second grade leveling precision are: 60 m ≤ horizontal distance ≤ 1100 m and vertical angle ≤ ±60°. Along with the increase of horizontal distance, the table does not list the calculation of these increasing horizontal distances that can meet the requirements of this tolerance. In addition, if vertical angle ≤ ±20°, horizontal distance can be extended to be within the range of 50 m ≤ horizontal distance ≤ 1300 m and can meet the requirements of second grade leveling tolerance too.

Table 9. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 50 m horizontal distance of 1” total station instrument.*

50 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	1.36	1.28	1.22	1.20	1.20	1.20	1.22	1.28	1.36
–40	1.30	1.22	1.15	1.13	1.12	1.13	1.15	1.22	1.30
–20	1.25	1.16	1.09	1.06	1.06	1.06	1.09	1.16	1.25
–10	1.24	1.14	1.07	1.04	1.04	1.04	1.07	1.14	1.24
0	1.23	1.14	1.06	1.04	1.03	1.04	1.06	1.14	1.23
10	1.24	1.14	1.07	1.04	1.04	1.04	1.07	1.14	1.24
20	1.25	1.16	1.09	1.06	1.06	1.06	1.09	1.16	1.25
40	1.30	1.22	1.15	1.13	1.12	1.13	1.15	1.22	1.30
60	1.36	1.28	1.22	1.20	1.20	1.20	1.22	1.28	1.36
Note: $4\sqrt{K} = 1.265$ mm									

Table 10. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 60 m horizontal distance of 1” total station instrument.*

60 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	1.37	1.29	1.23	1.21	1.20	1.21	1.23	1.29	1.37
–40	1.31	1.23	1.16	1.14	1.13	1.14	1.16	1.23	1.31
–20	1.27	1.17	1.10	1.08	1.07	1.08	1.10	1.17	1.27
–10	1.25	1.16	1.08	1.06	1.05	1.06	1.08	1.16	1.25
0	1.25	1.15	1.07	1.05	1.04	1.05	1.07	1.15	1.25
10	1.25	1.16	1.08	1.06	1.05	1.06	1.08	1.16	1.25
20	1.27	1.17	1.10	1.08	1.07	1.08	1.10	1.17	1.27
40	1.31	1.23	1.16	1.14	1.13	1.14	1.16	1.23	1.31
60	1.37	1.29	1.23	1.21	1.20	1.21	1.23	1.29	1.37
Note: $4\sqrt{K} = 1.386$ mm									

Table 11. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 1,100 m horizontal distance of 1" total station instrument.*

1100 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	3.38	3.22	3.15	3.13	3.12	3.13	3.15	3.22	3.38
–40	4.62	4.42	4.34	4.32	4.31	4.32	4.34	4.42	4.62
–20	5.47	5.25	5.16	5.14	5.14	5.14	5.16	5.25	5.47
–10	5.69	5.46	5.38	5.36	5.35	5.36	5.38	5.46	5.69
0	5.77	5.54	5.45	5.43	5.43	5.43	5.45	5.54	5.77
10	5.69	5.46	5.38	5.36	5.35	5.36	5.38	5.46	5.69
20	5.47	5.25	5.16	5.14	5.14	5.14	5.16	5.25	5.47
40	4.62	4.42	4.34	4.32	4.31	4.32	4.34	4.42	4.62
60	3.38	3.22	3.15	3.13	3.12	3.13	3.15	3.22	3.38
Note: $4\sqrt{K} = 5.933$ mm									

Table 12. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 1,300 m horizontal distance of 1" total station instrument.*

1300 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	3.86	3.69	3.62	3.60	3.59	3.60	3.62	3.69	3.86
–40	5.36	5.15	5.06	5.05	5.04	5.05	5.06	5.15	5.36
–20	6.39	6.15	6.06	6.04	6.03	6.04	6.06	6.15	6.39
–10	6.66	6.41	6.32	6.30	6.29	6.30	6.32	6.41	6.66
0	6.75	6.50	6.41	6.39	6.38	6.39	6.41	6.50	6.75
10	6.66	6.41	6.32	6.30	6.29	6.30	6.32	6.41	6.66
20	6.39	6.15	6.06	6.04	6.03	6.04	6.06	6.15	6.39
40	5.36	5.15	5.06	5.05	5.04	5.05	5.06	5.15	5.36
60	3.86	3.69	3.62	3.60	3.59	3.60	3.62	3.69	3.86
Note: $4\sqrt{K} = 6.450$ mm									

3.1.5. Apply 0.5" Precision Total Station Instrument to Observe Performance of Root Mean Square Errors (RMSEs) in Elevation Difference

Take $m_v = 1$ mm, $m_\alpha = 0.5"$ and calculate ranging error by 0.5 mm+1 ppm. The data in the shaded area in Table 13–16 just indicate the area meeting the requirements of second grade leveling precision. Experimental results show that this precision instrument can meet the requirements of second grade leveling tolerance under the condition of 40 m ≤ horizontal distance ≤ 4200 m and the condition of all vertical angles at front viewing point and at rear viewing point ≤ ±60°. This working condition can basically satisfy the requirements of high-grade precision elevation surveying within the value range of vertical angles under general conditions. This condition has a good reference value for high grade elevation surveying in mountainous areas. The table does not list the calculation of these horizontal distances that can meet conditions.

The shaded area in Table 17–20 shows the data that can meet the requirements of first grade leveling precision. The conditions are: 250 m ≤ horizontal distance ≤ 600 m and all vertical angles at front viewing point and at rear viewing point ≤ ±50°. This condition has a good reference value for middle & high grade precision elevation surveying in special engineering construction projects, such as water conservancy projects, bridge projects and large equipment installation projects, etc.

Table 13. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 35 m horizontal distance of 0.5" total station instrument.*

35 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	1.10	1.08	1.06	1.06	1.05	1.06	1.06	1.08	1.10
–40	1.09	1.06	1.04	1.03	1.03	1.03	1.04	1.06	1.09
–20	1.07	1.04	1.02	1.01	1.01	1.01	1.02	1.04	1.07
–10	1.06	1.04	1.01	1.01	1.01	1.01	1.01	1.04	1.06
0	1.06	1.03	1.01	1.01	1.00	1.01	1.01	1.03	1.06
10	1.06	1.04	1.01	1.01	1.01	1.01	1.01	1.04	1.06
20	1.07	1.04	1.02	1.01	1.01	1.01	1.02	1.04	1.07
40	1.09	1.06	1.04	1.03	1.03	1.03	1.04	1.06	1.09
60	1.10	1.08	1.06	1.06	1.05	1.06	1.06	1.08	1.10
Note: $4\sqrt{K} = 1.058$ mm									

Table 14. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 40 m horizontal distance of 0.5" total station instrument.*

40 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	1.11	1.08	1.06	1.06	1.05	1.06	1.06	1.08	1.11
–40	1.09	1.06	1.04	1.03	1.03	1.03	1.04	1.06	1.09
–20	1.07	1.04	1.02	1.01	1.01	1.01	1.02	1.04	1.07
–10	1.07	1.04	1.02	1.01	1.01	1.01	1.02	1.04	1.07
0	1.07	1.04	1.01	1.01	1.00	1.01	1.01	1.04	1.07
10	1.07	1.04	1.02	1.01	1.01	1.01	1.02	1.04	1.07
20	1.07	1.04	1.02	1.01	1.01	1.01	1.02	1.04	1.07
40	1.09	1.06	1.04	1.03	1.03	1.03	1.04	1.06	1.09
60	1.11	1.08	1.06	1.06	1.05	1.06	1.06	1.08	1.11
Note: $4\sqrt{K} = 1.131$ mm									

Table 15. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 4,200 m horizontal distance of 0.5" total station instrument.*

4200 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	6.59	6.11	5.97	5.94	5.93	5.94	5.97	6.11	6.59
–40	9.19	8.42	8.20	8.16	8.15	8.16	8.20	8.42	9.19
–20	10.97	10.02	9.75	9.70	9.69	9.70	9.75	10.02	10.97
–10	11.43	10.44	10.16	10.11	10.09	10.11	10.16	10.44	11.43
0	11.59	10.59	10.30	10.25	10.23	10.25	10.30	10.59	11.59
10	11.43	10.44	10.16	10.11	10.09	10.11	10.16	10.44	11.43
20	10.97	10.02	9.75	9.70	9.69	9.70	9.75	10.02	10.97
40	9.19	8.42	8.20	8.16	8.15	8.16	8.20	8.42	9.19
60	6.59	6.11	5.97	5.94	5.93	5.94	5.97	6.11	6.59
Note: $4\sqrt{K} = 11.593$ mm									

Table 16. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 4,400 m horizontal distance of 0.5" total station instrument.*

4400 m	α_B (°)								
α_A (°)	**–60**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**60**
–60	6.89	6.39	6.24	6.21	6.20	6.21	6.24	6.39	6.89
–40	9.61	8.81	8.58	8.54	8.53	8.54	8.58	8.81	9.61
–20	11.48	10.49	10.21	10.16	10.14	10.16	10.21	10.49	11.48
–10	11.97	10.93	10.64	10.59	10.57	10.59	10.64	10.93	11.97
0	12.13	11.08	10.79	10.73	10.71	10.73	10.79	11.08	12.13
10	11.97	10.93	10.64	10.59	10.57	10.59	10.64	10.93	11.97
20	11.48	10.49	10.21	10.16	10.14	10.16	10.21	10.49	11.48
40	9.61	8.81	8.58	8.54	8.53	8.54	8.58	8.81	9.61
60	6.89	6.39	6.24	6.21	6.20	6.21	6.24	6.39	6.89
Note: $4\sqrt{K} = 11.730$ mm									

Table 17. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 200 m horizontal distance of 0.5" total station instrument.*

200 m	α_B (°)										
α_A (°)	**–60**	**–50**	**–30**	**–20**	**–10**	**0**	**10**	**20**	**30**	**50**	**60**
–60	1.19	1.17	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.17	1.19
–50	1.21	1.18	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.18	1.21
–30	1.23	1.19	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.19	1.23
–20	1.23	1.19	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.19	1.23
–10	1.24	1.19	1.14	1.12	1.11	1.11	1.11	1.12	1.14	1.19	1.24
0	1.24	1.20	1.14	1.12	1.11	1.11	1.11	1.12	1.14	1.20	1.24
10	1.24	1.19	1.14	1.12	1.11	1.11	1.11	1.12	1.14	1.19	1.24
20	1.23	1.19	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.19	1.23
30	1.23	1.19	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.19	1.23
50	1.21	1.18	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.18	1.21
60	1.19	1.17	1.14	1.12	1.12	1.11	1.12	1.12	1.14	1.17	1.19
Note: $1.8\sqrt{K} = 1.138$ mm											

Table 18. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 250 m horizontal distance of 0.5" total station instrument.*

250 m	α_B (°)										
α_A (°)	**–60**	**–50**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**50**	**60**
–60	1.23	1.20	1.18	1.15	1.14	1.14	1.14	1.15	1.18	1.20	1.23
–50	1.25	1.22	1.19	1.16	1.15	1.15	1.15	1.16	1.19	1.22	1.25
–40	1.27	1.23	1.20	1.17	1.16	1.15	1.16	1.17	1.20	1.23	1.27
–20	1.31	1.26	1.22	1.18	1.17	1.16	1.17	1.18	1.22	1.26	1.31
–10	1.32	1.26	1.23	1.18	1.17	1.17	1.17	1.18	1.23	1.26	1.32
0	1.32	1.26	1.23	1.18	1.17	1.17	1.17	1.18	1.23	1.26	1.32
10	1.32	1.26	1.23	1.18	1.17	1.17	1.17	1.18	1.23	1.26	1.32
20	1.31	1.26	1.22	1.18	1.17	1.16	1.17	1.18	1.22	1.26	1.31
40	1.27	1.23	1.20	1.17	1.16	1.15	1.16	1.17	1.20	1.23	1.27
50	1.25	1.22	1.19	1.16	1.15	1.15	1.15	1.16	1.19	1.22	1.25
60	1.23	1.20	1.18	1.15	1.14	1.14	1.14	1.15	1.18	1.20	1.23
Note: $1.8\sqrt{K} = 1.273$ mm											

Table 19. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 600 m horizontal distance of 0.5" total station instrument.*

600 m	α_B (°)										
α_A (°)	**–60**	**–50**	**–40**	**–20**	**–10**	**0**	**10**	**20**	**40**	**50**	**60**
–60	1.56	1.50	1.47	1.42	1.41	1.41	1.41	1.42	1.47	1.50	1.56
–50	1.68	1.61	1.56	1.51	1.50	1.49	1.50	1.51	1.56	1.61	1.68
–40	1.80	1.71	1.66	1.60	1.58	1.58	1.58	1.60	1.66	1.71	1.80
–20	1.98	1.87	1.80	1.73	1.72	1.71	1.72	1.73	1.80	1.87	1.98
–10	2.03	1.91	1.84	1.77	1.76	1.75	1.76	1.77	1.84	1.91	2.03
0	2.05	1.93	1.86	1.79	1.77	1.77	1.77	1.79	1.86	1.93	2.05
10	2.03	1.91	1.84	1.77	1.76	1.75	1.76	1.77	1.84	1.91	2.03
20	1.98	1.87	1.80	1.73	1.72	1.71	1.72	1.73	1.80	1.87	1.98
40	1.80	1.71	1.66	1.60	1.58	1.58	1.58	1.60	1.66	1.71	1.80
50	1.68	1.61	1.56	1.51	1.50	1.49	1.50	1.51	1.56	1.61	1.68
60	1.56	1.50	1.47	1.42	1.41	1.41	1.41	1.42	1.47	1.50	1.56
Note: $1.8\sqrt{K} = 1.972$ mm											

Table 20. *Elevation difference root mean square errors (RMSEs) at all vertical angles at 650 m horizontal distance of 0.5" total station instrument.*

650 m	α_B (°)										
α_A (°)	**–60**	**–50**	**–30**	**–20**	**–10**	**0**	**10**	**20**	**30**	**50**	**60**
–60	1.62	1.55	1.49	1.47	1.46	1.45	1.46	1.47	1.49	1.55	1.62
–50	1.76	1.67	1.59	1.57	1.56	1.55	1.56	1.57	1.59	1.67	1.76
–30	2.00	1.89	1.79	1.76	1.74	1.74	1.74	1.76	1.79	1.89	2.00
–20	2.09	1.97	1.86	1.83	1.81	1.81	1.81	1.83	1.86	1.97	2.09
–10	2.15	2.02	1.90	1.87	1.86	1.85	1.86	1.87	1.90	2.02	2.15
0	2.17	2.04	1.92	1.89	1.87	1.87	1.87	1.89	1.92	2.04	2.17
10	2.15	2.02	1.90	1.87	1.86	1.85	1.86	1.87	1.90	2.02	2.15
20	2.09	1.97	1.86	1.83	1.81	1.81	1.81	1.83	1.86	1.97	2.09
30	2.00	1.89	1.79	1.76	1.74	1.74	1.74	1.76	1.79	1.89	2.00
50	1.76	1.67	1.59	1.57	1.56	1.55	1.56	1.57	1.59	1.67	1.76
60	1.62	1.55	1.49	1.47	1.46	1.45	1.46	1.47	1.49	1.55	1.62
Note: $1.8\sqrt{K} = 2.052$ mm											

3.2. The Applicable Conditions for Elevation Surveying of Total Station Instrument at Different Grades

In the case of observation by plunging telescope, the total station instruments at all grades are applicable to the requirements of leveling precision at different grades, as shown in Table 21.

Table 21. *The conditions for total station instruments with different precisions to meet requirements of leveling precision at different grades.*

Total station instrument	Angle measuring precision 0.5”		Angle measuring precision 1”		Angle measuring precision 2”	
	Distance measurement precision 0.5 mm+1 ppm		Distance measurement precision 1 mm+1 ppm		Distance measurement precision 2 mm+2 ppm	
	Vertical angle (°)	Horizontal Distance HD (m)	Vertical angle (°)	Horizontal Distance HD (m)	Vertical angle (°)	Horizontal Distance HD (m)
Meet first grade leveling precision	≤±50	250≤HD≤600				
Meet second grade leveling precision	≤±60	40≤HD≤4200	≤±60	60≤HD≤1100		
Meet third grade leveling precision	≤±60	No limit	≤±60	No limit	≤±60	20≤HD≤2800

3.3. The Applicable Conditions for High Precision Elevation Surveying of Leica TS60 and Nova TS50 Ultra-high Precision Total Station Instruments

For Leica TS60 and Nova TS50 Ultra-high Precision Total Station Instruments, their angle measuring precision is 0.5”, their ranging precision is 0.6 mm+1 ppm, standard prism mode distance measurement range is from 1.5 m to 3,500 m. In the circumstance of applying “intermediate ranging mode” under the observation by means of plunging telescope, the applicable conditions for it to meet requirements of high precision elevation surveying are shown in Table 22.

Table 22. *The applicable conditions for Leica TS60 and Nova TS50 total station instruments to meet high grade elevation surveying.*

	Vertical angle conditions (°)	Conditions for side length and Horizontal Distance HD (m)	Distance measurement range (m)
Meet first grade leveling precision	≤±50	270≤HD≤630	1.5–3500
Meet second grade leveling precision	≤±60	45≤HD≤3500	
Meet third grade leveling precision	≤±60	No limit	

4. Conclusion

I. It is feasible to carry out high-precision elevation surveying with the intermediate ranging mode of total station instrument. The higher the precision of total station instrument, the higher the elevation surveying precision that can be satisfied will be. However, it is necessary to strictly follow the established observation procedures and conditions. Especially in the observation in which the precision of leveling precision can reach the first or second grade, the related conditions should be strictly controlled. It mainly includes:

(1) Observation by plunging telescope shall be carried out at each survey station;

(2) Under the observation requirements on different grades, the difference between horizontal distances at front viewing point and at rear viewing point shall be controlled according to Table 1, which is generally controlled at less than 5 m;

(3) Under the observation requirements on different grades, the discrepancy of elevation difference observed by plunging telescope at survey station 1 shall be controlled according to Table 4;

(4) Under the observation requirements on different grades, the selection of total station instrument shall be controlled according to Table 21.

II. The conventional precision total station instrument with angle measuring precision of 2” and ranging precision of 2 mm+2 ppm can only be used for the observation with requirements on leveling precision at third grade or below third grade.

The high precision total station instrument with angle measuring precision of 1” and ranging precision of 1 mm+1 ppm can only be used for the observation with requirements on leveling precision at second grade or below second grade; and at the time of conducting observation with requirements on leveling precision at second grade, the vertical angle shall be smaller than 60° and the horizontal distance between side lengths at front viewing point and rear viewing point shall be within the range of 60–1100 m.

The ultra-high precision total station instrument with angle measuring precision of 0.5” and ranging precision of 0.5 mm+1 ppm can be used for the observation with requirements on first grade leveling precision. Considering that Leica TS60 and Nova TS50 Ultra-high Precision Total Station Instruments that are currently available for engineering applications have the ranging precision of 0.6 mm+1 ppm and distance measurement range of 1.5–3500 m, the applicable conditions for elevation surveying with requirements on first grade leveling precision are as follows: the vertical angle shall be smaller than 50°, the horizontal distance between side lengths shall be greater than or equal to 270 m and less than or equal to 630 m.

III. The method of intermediate ranging mode elevation surveying of total station instrument can only read “VD” (Vertical Distance) value and prism height v in “Distance Measurement”. What is mainly related to the operation skills of observer is the aiming (sighting) process, so aiming errors shall be strictly controlled in the surveying process.

IV. The method of intermediate ranging mode elevation surveying of total station instrument can provide effective high-precision elevation observation schemes for elevation surveying with long distance and large elevation difference, long-distance elevation transmission and elevation surveying in mountainous areas and it has good popularization and application value.

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Studija o prilagodljivosti visokopreciznih mjerenja visinskih razlika metodom mjerenja iz sredine primjenom geodetske mjerne stanice

SAŽETAK. Pojavom preciznih geodetskih mjernih stanica omogućena je njihova primjena u visokopreciznom mjerenju visina. Za razliku od tradicionalne metode trigonometrijskog nivelmana, "metodom mjerenja visinskih razlika geodetskom mjernom stanicom iz sredine" mjere se samo udaljenosti bez mjerenja kutova ili visine instrumenta, što može velikim dijelom povećati preciznost opažanja. Trenutno su prisutna dva problema u postojećim relevantnim teorijskim i praktičnim istraživanjima: prvo, u raspravama o točnosti mjerenja koja se postiže ovom metodom, velik dio literature prikazuje samo dio analitičkih podataka, no rijetko uključuje konkretne i sveobuhvatne podatke. Drugo, ima puno rasprava o analizi izvedivosti mjerenja visoke preciznosti, ali samo nekoliko o tome kako provesti određena mjerenja i čemu treba posvetiti pažnju u praksi. U pogledu gore navedenoga, u ovom radu provodi se analiza i istraživanje utjecaja raznih faktora kao što su preciznost, kosa duljina i vertikalni kut na preciznost visinske razlike u "metodi mjerenja visinskih razlika geodetskom mjernom stranicom iz sredine" te daju primjenjivi uvjeti za korištenje geodetskih mjernih stanica različite preciznosti kako bi se provelo mjerenje visina u različitim redovima nivelmana. To znatno doprinosi popularizaciji i vrijednosti primjene mjerenja visine visoke preciznosti u okolnostima velike visinske razlike i velike udaljenosti.

Ključne riječi: *geodetska mjerna stanica, mjerenje iz sredine, precizno mjerenje visina, primjenjivost.*

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