Application and analysis of inverted ruler method in vault settlement monitoring of underground excavation station

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Abstract. In the urban rail transit engineering, the construction of undercutting under the existing rail line is plagued by high construction risk and high monitoring accuracy requirements. Taking a station A in an urban rail transit project as an example, combined with the characteristics of the project, the monitoring scheme of vault settlement in the excavation section is formulated. In order to establish two sets of relatively independent elevation system and adopt the method of setting up independent station to measure the inverted ruler, the feasibility of this method is verified, and the sources of measurement error and control measures are analyzed. The actual results show that the method can meet the requirements of monitoring accuracy of vault settlement in the underground excavation section of subway station.

1. Introduction
In recent years, with the rapid development of urban rail transit, the construction requirements and difficulties of urban rail transit project are bigger and bigger. The staggered complexity of various lines leads to the construction difficulty of the station without considering the pre left crossing condition, and at the same time, it leads to the difficulty of engineering monitoring. In the field of urban rail transit engineering, how to effectively complete the settlement monitoring in the construction process of similar stations has always been the focus of attention. The existing automatic monitoring technology is often used in the settlement monitoring of the station. However, due to the constraints of the construction environment, the monitoring effect is often difficult to achieve the expected goal in the crisscross and complex existing lines. Therefore, how to ensure the monitoring accuracy is very important for the monitoring of the vault settlement in the undercut section of the existing railway station.

Taking the monitoring of station A in a project as an example, in order to ensure the monitoring accuracy to meet the requirements of relevant specifications, a method for monitoring the settlement of underground excavation section is designed. The practical test shows that the operation is convenient, the effect is good, and the measurement accuracy meets the specification requirements.
2. Project Overview
The location relationship between station A and the existing line is in the shape of "cross". Under the existing station, the two stations transfer through the transfer hall, and the Undercrossing part adopts the flat roof vertical wall excavation method. The underground excavation structure of XX station is 24m in length, 23.9m in width and 11.59m in height. The buried depth of the top of the underground excavation section is 17.3m. The inner layers of the excavation range are strongly weathered mudstone and moderately weathered mudstone. The concealed excavation section is divided into three large guide holes in the right, left, and middle, with a total of 10 holes.

3. Monitoring programme
According to the characteristics of underground excavation, the total station trigonometric leveling method is usually used to monitor the settlement of arch crown. The forced centering plate is configured and the elevation transmission is used. However, due to the complex site environment of the project, the monitoring control accuracy is high (arch settlement control value of 4mm, warning value of 2mm) [1-2]. After the actual operation of this method, the observation error is large, and it is difficult to ensure the monitoring accuracy. Therefore, due to the structural characteristics of the observation tower ruler, the observation accuracy cannot meet the requirements of the design document.

In this project, it is necessary to develop a method and equipment which can not only adapt to the complex operation environment, but also ensure the monitoring accuracy. Finally, the methods of electronic level, inverted indium steel ruler and special devices are used to monitor the vault settlement in the excavation section of station A. The advantages of this scheme are as follows: (1) using high-precision indium steel ruler, non-traditional tower ruler; (2) specially designed a hanging conversion connection device of indium steel ruler to ensure the vertical and stability of the ruler.

3.1. Set up control network
In station A, two settlement reference points JZ01 and JZ02 are arranged on the two columns far away from the underground section. The columns at this position are integrated with the floor of the station, and the concrete casting has been completed for more than 3 months, so the influence of its own settlement can be ignored. Two settlement working points GZ01 and GZ02 are arranged on the two columns close to the excavation section in station A, considering the need of settlement observation on the vault of underground excavation section, GZ01' and GZ02' are respectively arranged above GZ01 and GZ02. The control network of this method consists of two elevation datum points and four elevation working base points.

JZ01, JZ02, GZ01 and GZ02 are buried under the side of the column with "L" type nail drilling holes, which are convenient for measuring personnel. GZ01' and GZ02' use indium steel rule settlement paste and stick it on the wall. The datum point shall be set outside the influence scope of construction to avoid collision and damage in construction cross operation. In order to ensure that the datum point is firm and reliable, it is better to use strong glue to block again. At the same time, technical disclosure should be made to the site construction personnel to strengthen the point protection to ensure the continuity of the monitoring process.

Figure 1. Schematic diagram of elevation reference point control network layout
3.2. Instrument and equipment

In order to ensure the monitoring accuracy, high-precision measuring instruments are used in the selection of instruments. Trimble Dini 03 digital level with accuracy of 0.3 mm / km is selected. A set of indium steel ruler, tripod and designed indium steel ruler are used for hanging conversion connection device, settlement monitoring stickers and "L" type monitoring nails.

3.3. Monitoring elevation control

In the field of deformation monitoring, it is often focused on the change and cumulative change of the monitoring target, which need not be carried out in absolute coordinate system [3]. The monitoring of urban rail transit engineering also does not explicitly require the use of absolute elevation system. In this project application, the relative independent elevation system is still used [4].

Two sets of independent elevation control systems are established on the basis of considering the site environment, point position relation and the characteristics of underground excavation. The first is the elevation system of working base point. The elevation of JZ01 is set as 100m, and JZ01, JZ02, GZ01 and GZ02 constitute the elevation system of working base point. The other is the monitoring elevation system. The elevation of GZ01 'point is set as 101m, and the monitoring points such as GZ01', GZ02 ', GD01 and GD02 form the monitoring elevation system together. The two elevation systems are independent of each other without any connection.

3.4. Monitoring process

The concrete process of arch settlement monitoring based on the inverted scale method is as follows:

![Monitoring flowchart](image)

(1) Stagger the construction period and set up the datum network of elevation. The elevation of JZ01 point was set as 100m, and the elevations of JZ02, GZ01 and GZ02 were measured using Trimble Dini 03 level. The observation sequence is JZ01 ~ GZ01 ~ GZ02 ~ JZ02. The elevation of GZ01 ‘point was set as 101m, and the elevation of GZ02’ is measured using Trimble Dini 03 level. The position relationship of each point is determined.

(2) During the construction of underground excavation, according to the excavation progress, timely arrange the arch crown settlement monitoring points, coordinate the construction units to carry out the point acceptance and elevation value confirmation, and pay attention to the protection of monitoring points to ensure the continuity of monitoring.

(3) When monitoring the settlement of the arch roof in the subsurface section, the indium steel rule hanging conversion connection device should be laid flat, the adjusting screw should be unscrewed completely, the indium steel rule should be put into the bottom of the device gently, and the screw should be screwed down so that the indium steel rule can be fixed. Then connect the connecting sleeve to the connecting rod smoothly, and ensure that the stainless steel ball can move normally within the
sleeve. According to the height of the monitoring environment, the connecting rods are spliced until the length of the connecting rods meets the site requirements. Finally, connect the connecting rod with the monitoring rod to complete the assembly of the device.

(4) The assembled device is hoisted to a hook at the settlement monitoring point on the dome, and a special structure of the stainless steel ball allows the indium steel ruler to be slowly rotated to better align the observation surface with the level. Adjust the indium steel ruler to be upright and keep stable, set up the level to complete the measurement, and get the elevation value of GD01, GD02, etc. of the monitoring points. The horizontal observation sequence is GZ01 ~ GD0i ~ GZ02.

(5) After observing the elevation of all monitoring points, dismantle the measuring device, maintain the measuring equipment, sort out the measurement data, and calculate the elevation change of the monitoring point.

Table 1. Monitoring elevation data

| Point Name | 2020/9/26 | 2020/10/3 | 2020/10/10 | 2020/10/17 | 2020/10/24 | 2020/10/31 | 2020/11/7 |
|------------|-----------|-----------|------------|------------|------------|------------|-----------|
| GD01       | 104.24357 | 104.24219 | 104.24213  | 104.24224  | 104.24240  | 104.24263  | 104.24260 |
| GD02       | 104.22286 | 104.21882 | 104.21858  | 104.21837  | 104.21848  | 104.21816  | 104.21875 |

According to formula (1), the cumulative settlement variation of GD01 and GD02 at the monitoring point is calculated.

\[ \Delta H = H_i - H_0 \]  

The accumulated settlement change data of monitoring point GD01 and monitoring point GD02 in one month are shown in Table 2.

Table 2. Accumulated settlement change

| Point Name | 2020/10/3 | 2020/10/10 | 2020/10/17 | 2020/10/24 | 2020/10/31 | 2020/11/7 |
|------------|-----------|------------|------------|------------|------------|-----------|
| GD01       | -7.52     | -7.58      | -7.47      | -7.31      | -7.08      | -7.11     |
| GD02       | -4.48     | -4.72      | -4.93      | -4.82      | -5.14      | -4.55     |

4. The error analysis

According to the measurement process and data analysis, the possible sources of errors are as follows:

1) Operating base point setting error: The working base point is set near the excavation section. Although the concrete pouring of the bottom slab has been completed for more than three months and the settlement is ignored, it cannot guarantee the absolute stability or not be damaged. Therefore, it is necessary to check the working base point regularly. Through the joint measurement of JZ01, JZ02, GZ01 and GZ02, the stability of the elevation value of each monitoring point can be guaranteed. At the same time, GZ01 and GZ02 are measured, and the stability of GZ01 ‘and GZ02’ can be determined.
indirectly through position relationship. When the elevation of working base point changes or is damaged, it can be corrected and repaired by the elevation of other working base points.

(2) Indium steel ruler suspension error: When the ruler is suspended for measurement, it may appear the phenomenon of hanging tilt, which cannot guarantee the complete vertical state, and the measurement error caused by the poor hanging state will occur. In order to avoid the occurrence of this phenomenon, the measurement personnel should be in the suspension after completion, check whether the indium steel ruler bubble is centered, whether other parts of the device have loose phenomenon, when the measurement to exclude other human factors interference.

(3) Measurement error: in the traditional leveling mode, the measurement data will have redundant error. In this project, in order to avoid this error, the measurement mode of setting station in the middle position and observing the forward-looking monitoring point directly after the working base point is adopted to avoid the cumulative error and the i-angle error of digital level to the maximum extent.

(4) Instrument error: Under the influence of the construction environment, the temperature and humidity are too high, and the air pressure is too low, so that the measurement accuracy of the measuring instrument is affected to some extent. Therefore, the daily maintenance of the instrument is particularly important. At the same time, the indium steel ruler suspension conversion connection device is also a precision component, which is equivalent to a fixed measurement constant in the measurement. Once damaged in the measurement, it will also lead to distortion of the measurement data and decrease of the monitoring accuracy.

5. Conclusion
(1) In the field of deformation monitoring, the relatively independent coordinate system can be used to determine the position relationship of each monitoring point, and it is also convenient for calculation. The problem that the monitoring surface of the subsurface section is not in the same elevation with the datum point can also be avoided in the settlement monitoring of the arch roof of this subsurface excavation project. Regular joint measurement verification of the elevation system can effectively reduce the observation error of working base point and improve the measurement accuracy [5].

(2) In special working conditions and operating environments, in order to reduce measurement errors and improve monitoring accuracy, the traditional leveling mode can be changed and single point monitoring can be used to effectively avoid the accumulated error of the line and the i-angle error of the level.

(3) The modification of instruments and equipment and the beneficial improvement of monitoring methods can improve the operation efficiency and monitoring accuracy, but attention should be paid to the maintenance of instruments.

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