Application of settlement monitoring of underground excavation station vault based on inverted rule method

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Abstract. In the urban rail transit engineering, there is a great risk in the underground excavation construction of the existing railway station, and the monitoring accuracy of the underground excavation construction is very high. Taking station A of a project as the research object, combined with the construction situation and the structural characteristics of the station, this paper discusses the influencing factors of the vault settlement monitoring in the undercut section of the existing metro station, and formulates the vault settlement monitoring scheme in the undercut section. The feasibility of the method is verified by setting up two sets of independent elevation system and adopting the method of setting up a single station to measure the inverted ruler, and then the error control measures are given. The results show that the method can meet the accuracy requirements of the vault settlement monitoring in the underground excavation section of metro station. This method can provide some technical reference for the similar monitoring project of underground 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 more and more big. In the construction of transfer stations, there are more and more cases of passing through the existing railway stations. For such stations that do not consider the conditions of the existing railway stations in advance, both the construction and monitoring are more complex and more difficult than other projects. How to effectively complete the settlement monitoring in the construction process has always been the focus and difficulty of urban rail transit engineering. At present, the structural settlement in the existing railway station is often monitored automatically by measuring robot, at present this technology development is relatively mature. However, in the monitoring of the vault settlement in the undercut section of the existing railway station, due to the limitations of the site conditions, the measurement accuracy of the conventional construction monitoring method is often unable to achieve the expected effect. 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, one the premise of effectively improving the monitoring accuracy of the settlement of the arch, a monitoring method is designed to improve the monitoring accuracy of the settlement of the dome in the excavated section. Through practical application, the method has a good effect. While guiding the safety construction of subway, it can provide some reference for similar projects.

2. Project Overview
A station of a project is located under the existing metro line, forming a "cross" with the existing metro line. The transfer hall is used for transfer between the two stations, and the underground part of the existing subway line is constructed by the straight 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 (1m) and moderately weathered mudstone (10.59m). The concealed excavation section is divided into three large guide holes in the right, left, and middle, with a total of 10 holes.

3. Solution design and implementation
According to the characteristics of the excavation process of the concealed excavation section, the total station Trigonometric Height transfer method of the forced center panel is initially adopted for the settlement of the arch crown. However, due to the complexity of the concealed excavation section site and the high accuracy of the monitoring requirements (the control value of the settlement of the arch crown is 4mm and the early warning value is 2mm) [1-2], after the implementation of the site, the system error of the total station observation method is large, which cannot guarantee the accuracy of the monitoring. However, due to the structural characteristics of the tower ruler itself, the observation accuracy does not meet the requirements of the design documents.

It is necessary to develop a monitoring method which can adapt to the site environment and is easy to implement and has high monitoring accuracy in this section. To sum up: the method of electronic level, inverted indium steel ruler and special device is adopted for the settlement monitoring of the vault in the concealed excavation section of station A. The difference between this method and the conventional method is that: ① the conventional method uses tower ruler or steel tape, while this method uses high-precision indium steel ruler; ② the special device in the method is a specially customized and assembled high-precision indium steel ruler sleeve.

The assembled high-precision indium steel ruler sleeve is composed of nine parts: monitoring hook, stainless steel ball, connecting hole, connecting sleeve, connecting rod, monitoring rod, ruler sleeve, adjusting bolt and fixing nut. The detailed parameters of the indium steel ruler device are as follows: the diameter of the monitoring hook is about 8mm, the length is generally 100mm-150 mm, the diameter of the stainless steel ball is 20 mm, the diameter of the connecting hole is generally about 12 mm, the length of the connecting rod is 1000 mm, and the diameter of the connecting rod is about 30 mm, and the length of the monitoring rod is generally 100 mm-200 mm. The inner diameter of ruler sleeve is generally 100mm-110mm, the length of fixing nut is 10mm-20mm and the diameter is 20mm-30mm, and the length of adjusting bolt is 40mm-50mm.

3.1. Layout of monitoring control network
The open excavation section of station A has been capped. The settlement reference points jz01 and jz02 are respectively set at the lower part of the two columns at the end (West Side) of the station far away from the open excavation section. The reference points are located at the column of the station. Station floor and column structure are rigid structure. After 3 months of pouring, the settlement deformation is ignored. The settlement base points GZ01 and GZ02 are respectively set at the lower part of the two columns near the end of the underground excavation section (East Side) of the station. Considering the settlement observation needs of the vault on the underground excavation section, the settlement base points GZ01'and GZ02' are respectively set at the upper part of the two columns on the
east side. 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 at the bottom side of the station column to facilitate the measurement. The measuring points are composed of "L" type measuring nails. After drilling holes on the concrete structure of the station column, they are buried and fixed by pouring reinforcement glue into the holes. GZ01'and GZ02' are embedded on the wall of the station column. Considering the accuracy, the method of mapping and marking is required. The pre-made indium steel ruler patch is pasted on the wall to be monitored and sealed with waterproof glue.

The reference point shall be set in the concealed position as far as possible to prevent the collision and damage of heavy objects. The contact surface of the reference point shall be firmly adhered with anchoring agent or other gel to prevent loosening. The warning signs shall be made and installed to alert site staff and strengthen the point protection.

3.2. Instrument and equipment selection

The total design period of the underground excavation is 8 months, in which No. 1 guide tunnel will provide conditions for shield tunnelling on the right line after 6 months for the implementation of underground excavation, and the No. 2 tunnel will provide conditions for the left-line shield transit after 7 months for the implementation of the underground excavation. Because of the long construction period, the difficulty of construction and the high risk level, the instruments with high precision and small error must be selected. Therefore, a Trimble Dini 03 digital level is used in this solution, with an accuracy of 0.3mm / km, two indium steel rulers, a tripod, and an indium steel ruler cover device that can be assembled, monitoring settlement stickers and several "L" type monitoring pins.

3.3. Instrument and equipment selection

Generally speaking, the subway settlement monitoring only needs to get the single change, change rate and cumulative change of the monitoring point accurately, and the absolute elevation coordinate of the monitoring point is not clearly required [3]. In the monitoring of the vault settlement of this underground excavation section, the monitoring control network can adopt either the urban rail transit engineering elevation system or the assumed elevation system [4].

In combination with site conditions, special structure of Station Excavation and excavation process, two independent elevation systems are established in the project, the first of which is the working base point elevation system. Assuming the elevation of GZ01 point is 100m; JZ01, JZ02, GZ01 and GZ02 together constitute the elevation system of working base point. The second elevation system is monitoring elevation system. Assuming the elevation of GZ01' point is 101m, and GZ01', GZ02', GD01 and GD02 and other monitoring points together constitute the monitoring elevation system. There is no absolute relation between the two elevation systems and no reference relation between the elevation values.

3.4. Monitoring process

The specific process of crown settlement monitoring based on inverted rule method is as follows:
4. Error source analysis
According to the field operation and data analysis, the error sources of this method are as follows:

(1) In the early stage of the construction of the concealed excavation section, the elevation datum network shall be arranged. Set up instruments and fine adjust the level in the station. Assume that the elevation of JZ01 point is 100m, and get the elevation values of JZ02, GZ01 and GZ02 through levelling. The observation sequence is JZ01-GZ01-GZ02-JZ02. Assuming the elevation of gz01 point is 101m, the elevation value of gz02 can be obtained by levelling. The relative relationship between GZ01, GZ02, GZ01' and GZ02' was obtained.

(2) During the construction of concealed excavation section, according to the progress of the project and the approved monitoring plan, the vault settlement monitoring points shall be set up in time in the upper cavern of the concealed excavation section. Generally, the vault settlement monitoring points shall be connected with steel hooks and effective protection measures shall be taken. At the same time, all participating units shall be organized to carry out spot inspection on the monitoring points.

(3) When monitoring the settlement of the arch crown in the concealed excavation section, first place the indium steel ruler sleeve horizontally, screw out all the adjusting bolts, put the indium steel ruler gently to the bottom of the ruler sleeve, and screw in the indium steel ruler by adjusting the bolts to fix it. Then connect the connecting sleeve to the connecting rod smoothly, and ensure that the stainless steel ball can move normally in the sleeve. According to the excavation height of the cavern on the concealed excavation section, splice the connecting rod until the length of the connecting rod meets the site requirements. Finally, the connecting rod part is horizontally connected with the monitoring rod part to complete the assembly of the whole device.

(4) The monitoring personnel slowly lift the splicing complete monitoring device, and connect the monitoring hook with the vault settlement monitoring point of the concealed excavation section. Through the special structure of the stainless steel ball, the indium steel ruler observation surface can be better aligned with the instrument by slowly rotating the indium steel ruler. After the whole device is stable, the settlement observation of the vault can be carried out better to avoid large error caused by improper suspension of the device. The elevation values of the arch settlement monitoring points GD01, GD02 can be obtained by level measurement, and the level observation order is GZ0'-GD0i-GZ02'.

(5) When the observation of all monitoring points is completed, slowly remove the whole monitoring device, decompose parts, sort out monitoring instruments, and transportation and maintenance are arranged by special personnel. Sort out the observation data, prepare the monitoring report and conduct the engineering safety evaluation.
1. Working base point error: because the working base point is located near the concealed excavation section, it cannot be guaranteed that the working base point will not be damaged or the position will not change in the construction process, so it is necessary to review the working base point regularly. Since GZ01 'and GZ02' use the indium steel rule patch method, and are not on the same height plane with the reference point in the station, the working base points GZ01 and GZ02 located on the same neutral pillar are measured when the working base point is checked. The jz01-gz01-gz02-jz02 line mode is adopted for the annexed levelling. Through the measurement of gz01 and gz02, the stability of gz01 'and gz02' can be judged indirectly. When it is found that the elevation of the working base point changes or is damaged, it can be corrected and repaired in time through other points.

2. Indium steel ruler suspension error: in the process of indium steel ruler suspension, the phenomenon of indium steel ruler suspension tilt may appear. Therefore, in order to avoid the indium steel ruler suspension error, the monitoring personnel first check whether the stainless steel ball in the device can move freely after hanging the indium steel ruler. Then check whether the air bubble of the indium steel ruler is in the middle. Finally, the monitoring personnel shall check with the cross wire of the level eyepiece, monitoring can be conducted after confirming that the indium steel ruler is falling vertically and is stationary. At the same time, the monitoring personnel shall prevent the interference of the site construction personnel or other factors.

3. Observation error: there are accumulated errors in conventional monitoring line pattern and monitoring data. In order to improve the monitoring accuracy, the vault settlement monitoring mode of this scheme adopts the mode of setting stations in the middle, directly looking back at the working base point and looking forward to the observation monitoring point for measurement, so as to avoid the transmission error of monitoring line and the angle error of level “i” to the greatest extent.

4. Instrument and equipment error: due to the particularity of the environment, it is inevitable that the temperature, humidity, air pressure and other external factors will affect the accuracy of the monitoring instrument, so the daily maintenance of the instrument is particularly important. The assembled indium steel ruler set device is a precise component, which is equivalent to a fixed constant in the monitoring data. Once it is damaged in the daily monitoring and sorting, it will cause data error. Therefore, the maintenance and management of the monitoring device is particularly important.

5. Conclusion
(1) In practical work, establishing two independent elevation systems can better avoid the problem that the monitoring surface and the datum point are not on the same elevation. At the same time, two pairs of working base points (one group of working base points is fixed with indium steel ruler) are checked regularly, which can effectively reduce the observation error of working base points and improve the measurement accuracy [5].

(2) In a narrow space, by adjusting the position of the instrument, changing the traditional way of levelling observation line, and using the level to directly observe a single monitoring point, the transmission error of the monitoring line and the “i” error of the level can be effectively avoided.

(3) The assembled indium steel ruler set device can better ensure the monitoring accuracy, reduce the error, and meet the requirements of the vault settlement monitoring in the concealed excavation section.

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