TERRESTRIAL LASER SCANNING FOR DEFORMATION MONITORING OF THE THERMAL PIPELINE TRAVERSED SUBWAY TUNNEL ENGINEERING

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ABSTRACT:

As a kind of modern vehicle, more and more subway lines appear in order to meet the need of urban transportation. Abuilding Beijing subway line 10 is traversed by a thermal pipeline in China. To ensure the progress and safety of the subway tunnel, the deformation monitoring of the tunnel structure is necessary. The terrestrial laser scanning technology is applied to monitor the deformation of subway tunnel structure. The paper puts forward a method of three-dimension integral deformation monitoring of subway tunnel structure. This method can obtain the three-dimension integral deformation tendency, which help to provide mechanics analysis on the deformation of tunnel construction and provides the technical support for the design, construction and management. The monitoring project is introduced. Firstly, within the deformation district of subway tunnel, the annular closed survey control network is set along the line of the up-down rail. Secondly, put a set of cross section every 3m to 5m following the middle line of tunnel. Set the reflection sheets on the arch, vertical wall, rail subgrade, etc. Then collect the point clouds information by three-dimension lidar scanner. After data joint and registering, the three-dimension model of tunnel structure is established. Thirdly, adopt automatic electronic total station to monitor the deformation of tunnel structure by fixed stationing. Finally, according to data processing and analysis using a model interpolation method, the deformation of subway tunnel is fitted finally. Thus we can obtain the 3D image of the subway deformation in a precision, stereo and visual way.

1. INTRODUCTION

In order to alleviate the pressure of the ground transportation, more and more urban subway has been programmed or built in Beijing, China. It has shown us the advantages of safety, speediness, low power consumption, low pollution etc. Monitoring the deformation of subway tunnels is a principal means for selecting the appropriate excavation and support methods in the design. Besides, with the quick development of public facilities in Beijing, more and more civil engineering construction must lead to the deformation of the adjacent subway tunnel. It causes the severe influences to the stabilization and safety of the tunnel, thus endanger the whole urban transportation system. During the construction of periphery foundation ditch engineering and tunnel engineering, how to guarantee the safety of the subway tunnel has been the severe difficulty needed to be solved.

Determining shape and position changes occurred in engineering is one of an application area of survey. Temporary and permanent deformations occur in engineering structures due to natural and artificial forces (Clough, 1960). The basic requirements of tunnel deformation monitoring are: lay out monitoring benchmarks, monitoring targets timely, take measurements regularly, analyzes the survey data and feedback information to relative departments in time (Kavvadas, 1999).
The traditional monitoring method is to set monitoring cross sections on the deformation district of tunnel. Tunnel wall convergence (closure) between references points bolted on the tunnel walls is usually measured with standard metal tape extensometers. By surveying these monitoring points with convergence rule, electronic total station and leveling, we can monitor the deformation of the tunnel structure. Some

drawbacks exist here. First, the number of the monitoring points is limited, which can not reflect the deformation tendency. Load analysis of the deformation of tunnel structure is constricted and the corresponding reinforce measure is difficult to carry out. Second, the traditional one has not used the remote monitor method, so it disturbs the transportation of the subway to some extent. Third, measurement accuracy depends on the purposes of the deformation observation. In subway tunnel, the dim light, narrow space and the complicate environment do disturb the monitoring accuracy.

A method of three-dimension safety deformation monitoring for urban subway is put forward here. It can obtain the 3D digital data of the subway tunnel deformation, which do not interrupt the subway transportation. It can not only precisely monitor the deformation of the tunnel structure and get the tendency of subway deformation, but also provide mechanics analysis on tunnel structure and the rail. This method has been applied to the deformation monitoring of the Beijing subway line 10 (Anding rd. Station –Beitucheng east rd. Station).

2. DEFORMATION MONITORING METHOD

2.1 Model building

Lidar technology is also called three-dimension laser scanning technology, which is a new kind of non-touch surveying method. It can obtain the array geometric image of survey object from laser point clouds, which were emitted by scan prism and the quick laser ambulator. So the three-dimension space model can be made. This technology can obtain the three-dimension coordinates of one point without reflecting prism,

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and the speed can reach 100,000 points/second. This technology is well suited for many applications: industrial, architectural, civil surveying, urban topography, reverse engineering, archaeology.

The detailed monitoring project is introduced here:

1. Within the deformation district, set the annular closed survey control network along the middle line of the up-down rail.

2. The basic survey is carried out using electronic total station before the deformation to be observed can be expected to occur. The survey equipment being used should be tested before the first time surveying, after continuously use for 3-6 months the equipments should be tested again.

3. Put a set of cross section every 3m-8m following the middle line of tunnel. Set the reflection target on the arch, vertical wall, subgrade of the rail (As Fig.1 shows). Survey coordinates of these monitoring points by electronic total station. It is recommended that the first survey result should be figured out in the average of at two or three times of survey. All following surveys will be compared to the results of this survey. Furthermore these reflection points will be the registration point of point clouds data.
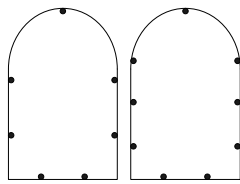

Figure 1. Reflection target setting

4. Collect the point clouds information of tunnel structure by three-dimension lidar scanner.

5. Based on the NURBS Curved face function (refer with: Eq.1), the three-dimension model of tunnel is established by the data process such as data joint and registering.

Let the order of polynomial is p × q, NURBS Curved face function can be written as:

$$S(u,v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n} w_{i,j} d_{i,j} N_{i,p}(u) N_{j,p}(v)}{\sum_{i=0}^{m}\sum_{j=0}^{n} w_{i,j} N_{i,p}(u) N_{j,p}(v)} \qquad (1)$$

Where $d_{i,j}(i=0,1,\cdots,m\; j=0,1,\cdots,n)$ represent the control vertex, and $w_{i,j}$ denotes the weight factor of vertex, and $N_{i,p(u)}, N_{j,q(v)}$ is gage B spline primary function.

2.2 Automatic monitoring

The 24 hour deformation monitoring is necessary to guarantee the safety of both the tunnel structure and transportation of the subway. Considering the high density of the subway's

transportation, we adopt the remote automatic monitor system to real-time monitor the tunnel structure, vertical wall, and subgrade of the rail by the Georobot.

2.2.1 Measurement principle of Georobot:
Georobot is often called automatic electronic total station (ETS). It is a kind of intelligent electronic total station, which is able to search target automatically, recognize, trace, collimate precisely and obtain the 3D coordinates (Tang, 2007).

Target points observation of tunnel deformation adopts free stationing principle of Georobot. Reflection sheets are set on the target points. To achieve higher resolution and improve reliability of observation data, Georobot can finish redundant observation automatically under the control of on-board software. Then adjustment of observation data of different periods, 3D coordinates values in different periods will be done by post-software of computer, finally we can get 3D coordinate displacement of target points: (ΔX, ΔY, ΔZ). For observation networks of free stationing, we choose indirect adjustment model to process data. Let t be necessary observation number and n be total observation number (n>t). Then adjustment model is:

$$\underset{t\times n}{B^T}\, \underset{n\times n}{P}\, \underset{n\times t}{B}\, \underset{t\times l}{\delta x} + \underset{t\times n}{B^T}\, \underset{n\times n}{P}\, \underset{n\times l}{l} = 0 \qquad (2)$$

taking $\underset{t\times t}{N} = \underset{t\times n}{B^T}\, \underset{n\times n}{P}\, \underset{n\times t}{B}, \underset{t\times l}{U} = \underset{t\times n}{B^T}\, \underset{n\times n}{P}\, \underset{n\times l}{l}$,

we get $\underset{t\times t}{N}\, \underset{t\times 1}{\delta x} + \underset{t\times 1}{U} = 0$, so that $\underset{t\times 1}{\delta x} = -\underset{t\times t}{N^{-1}}\, \underset{t\times 1}{U}$

The corresponding error equation by the matrix is:

$$\underset{n\times 1}{V} = \underset{n\times t}{B}\, \underset{t\times 1}{\delta x} + \underset{n\times 1}{l} \qquad (3)$$

where $\underset{n\times 1}{V} = [v_1, v_2 ...... v_n]^T$, $\underset{t\times 1}{\delta x} = [x_1, x_2, ... x_t]^T$, $\underset{n\times 1}{l} = [l_1, l_2 ...... l_n]^T = \underset{n\times 1}{d} - \underset{n\times 1}{L}$.

The above-mentioned method is that gets displacement by comparing coordinates of observation points. In the course of subway tunnel deformation analysis, we also consider lateral vector after observation value adjustment of different periods:

$$d_{ij}^{(k)} = [(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2]^{1/2}$$
$$\Delta d_{ij}^{(k)} - \Delta d_{ij}^{(k-1)} = \Delta_{k-1,k} \qquad (4)$$

Where, x_i , y_i , z_i are adjustment value. k is observation times of tunnel deformation, $\Delta_{k-1,k}$ is the convergence of measurement lines, they do not include error from possible displacement of base points, so they can accurately reflect tunnel deformation. By regressive analysis of these adjustment deformation values of different periods, we can conclude forecasting results of tunnel structure deformation.

2.2.2 The setting of Georobot:
The specially made instrument pier is put outside the right of the first rail. Georobot, i.e. fully automated motorized total stations under computer control to monitor remotely the three components of movement (Liu, 2008), is forced to be fixed on

the instrument pier through the pedestal and is protected with the glass cover. 6-16 reflecting sheets are installed for each monitoring station, which is distributed in the arch, vertical wall, orbit drainage ditch, rail fastener and so on. With the monitor program, Georobot collects the coordinates automatically and transports the data to the control server via data wire.

3. PROJECT APPLICATIONS

The thermal pipeline engineering of Beitucheng road traverses over the structure of Beijing subway line 10 (Anding rd. Station -- Beitucheng east rd. Station). The excavation of thermal pipeline causes the deformation of subway tunnel which is still under construction. The kilometer post of the tunnel deformation district is from K8+455 to K8+710. Figure 2 shows the profile view of the project. The distance of the subway tunnel and the thermal pipeline is very close; it ranged from 0.33m to 0.78m. It is great risk that the thermal pipeline crosses a subway tunnel with such close distance.
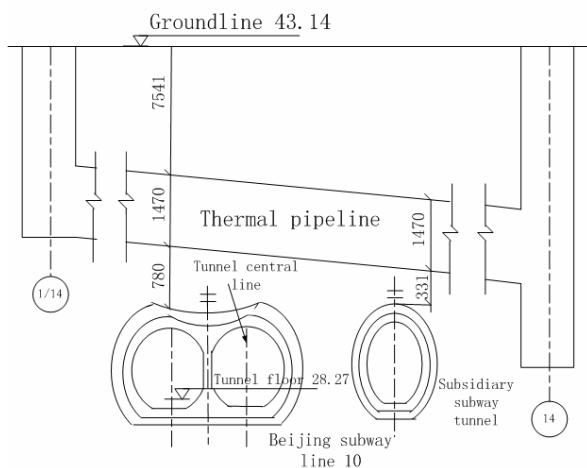

Figure 2. Sketch of project profile, showing the dimensions in mm
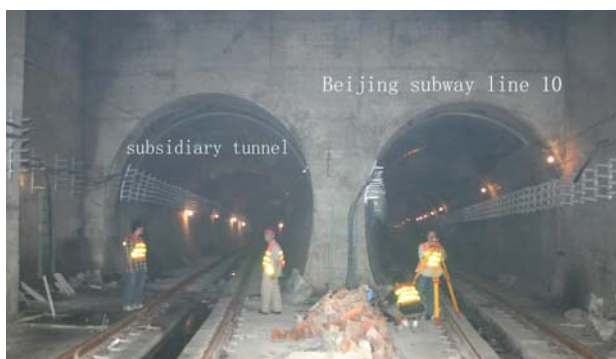

Figure 3. Monitoring site

Figure 3 shows the monitoring site. Terrestrial laser scanner (Leica HDS3000) was used to collect the point clouds information of subway tunnel structure. Five Leica TCA2003 automatic electronic total stations were mounted on tunnel structure. These Georobots were permanently sited on fixed location with vented heavy-duty glass enclosures to protect the system from the elements. Each installation included an intercom radio and modem with directional antenna to transmit data from the site to the controller.

The deformation monitoring results of subway line 10 are shown as follows: the accumulative deformation value of the max deformation point on the tunnel structure is +1.90mm; the max accumulative value of the rail deformation is +1.86mm; the max differential settlement of the rail subgrade is -0.29mm. So such conclusion can be made that the accumulative displacements of both tunnel structure and rail caused by the engineering construction are less than 2mm, which is within the allowed deformation range and put no influences on the subway transportation.

4. CONCLUSIONS

In order to protect the safety of subway tunnel, Real-time deformation monitoring must be taken. This method of three-dimension deformation monitoring has the advantages of high automation and three-dimensional measurement. It can be applied to the safety monitoring of high-rise building, side slope, deep foundation ditch project, and so on. Of course this method is not so mature. Its theory needs to be further researched through project experience. Moreover real-time monitoring is limited to cases where rapid response is absolutely necessary. Strict high-precise 3D automatic deformation monitoring has been one of the most important technical and safety supports.

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