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Structural Health Monitoring and Data Processing of Bracing of Foundation Pit

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Abstract: ***According to the technical feature of foundation pit structural health monitoring and the situation of the tunnel construction engineering project, a combination monitoring technique equipped by modern GPS technology and traditional survey methods is recommended. The efficient model focuses on the importance of safety monitoring in tunnel constructions. The issues about vertical and horizontal displacements incline deformation monitoring, network setting for foundation pit health monitoring, and processing are discussed in detail. The modern GPS technique is highly efficient for the reference network building while traditional survey method are usually limited by the condition of construction site. With the help of GPS technique, work efficiency and precision can be improved, and project quality will thus be guaranteed .The monitoring data analysis at the end of this paper not only demonstrates the necessity of safety monitoring, but also raise important questions for the structural health monitoring of foundation pit. These are very worthwhile reference for similar cases.***

Keywords: bracing structure; Deformation; GPS survey; Data processing

1. Introduction

The tunnel of the project is composed by U-tanks and box culverts. 1+568~1+638,1+794~1+864 are U-tanks. Each tank is 70m long and the width of banks is summed to 22m. 1+638~1+794 are box culverts .The sum of lengths of all box culverts reaches 156m. Equally divided it into 4parts , each box culvert is 38.25 m long and the width of all box culverts is summed to 21.4m .Reinforced concrete piles with diameter of ϕ100 steel pipe were taken as support .They are 21m long with concrete outside .the concrete piles with ϕ60@30 were dry form water. The depth of concrete pile is 10m. They connected to each other side by side. The steel in the shape of I is used as the inside supports. The distance between two supports is 6m wide. The depth of the foundation pit is 8m. Zheng G., Cheng X. S. and so on in the document literature initially proposed the foundation pit engineering redundancy definition and its design method framework [2].

2. Material and Methods

2.1 Monitoring Strategy

In order to pursue informational construction, the present study defined the accuracy of the horizontal displacement monitoring as third order and the vertical as second order based on the calculation of the safety criterion of the ancient engineering bridge. Further, employed a set of specific coordinates. Since, the sight condition of the construction site is not reliable, most reference nets can't be easily observed. Besides, the monitoring points and those reference nets are different heights. So, methods combine the modern survey with traditional monitoring methods together to accomplish the task. That will build the plane reference network by the modern GPS technique, and surveyed the horizontal displacement by T2 universal theodolite and the vertical displacement by high precision level instrument. Based on the two comparative schedules, layer monitoring and instant tracing rule was followed during the whole construction process. Surveying equipment used for study area has been illustrated in figure 1.

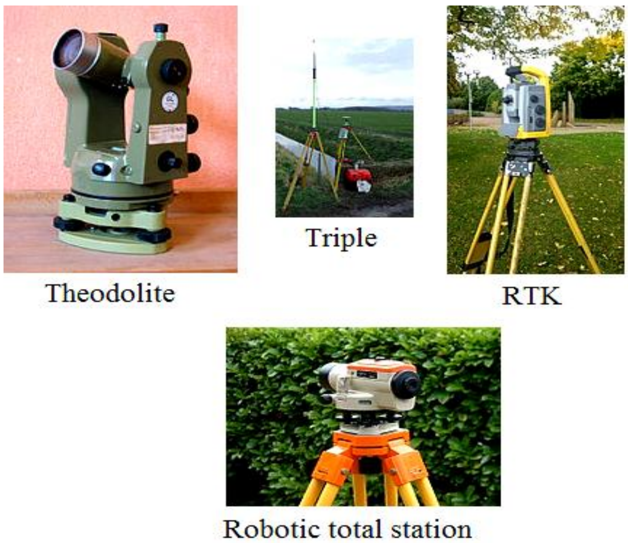

Figure 1: Surveying equipment used for study area

2.2. Reference Network Building

The reference nets are very important for the survey control system and usually built in the area outside and far from the construction site to maintain their stability. It is not be too far though for the consideration of having better monitoring accuracy and also for our convenience of work. Monitoring network is a second order control station; where first order network is composed by the reference nets and measured once a week to maintain its stability. Moreover, second order frame is set up to cover the monitoring target points and is frequently checked via the most stable reference nets. For that, five reference nets were set up; there are at the east

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bank and other two are at west bank of the ancient canal.

Figure 2:

Figure 2 reveal a survey using traverse and offset measurements to record the location of the shoreline shown in blue. Black dashed lines are traverse measurements between reference points (black circles). The red lines are offsets measured at right angles to the traverse lines.

2.3 Monitoring Points for Foundation Pit

Vertical and horizontal displacement monitoring targets at retaining wall, five point (namely W1~W5) are to be set up at the top of both side of retaining walls by buried needles. Although, monitoring points at the deep foundation slab for inclining survey; five monitoring target points named QX1~QX5, out of that four were at both sides of the foundation wall and was beside the engineering Brigde.

2.4. Monitoring Methods

2.4.1 Reference network survey

The plane reference network was surveyed for three times by following the official construction standards entitled "Global Positioning System for Urban Survey Technique Standards". Three single –frequency receivers were set up to receive the signal at the same time. These three 4600Ls GPS instruments are made in America. In order to check and to ensure the reliability of collected data, each observation was taken under the technical standards as shown in Table 1. An extra edge measurement was then taken by using electronic tachometer to check the reliability of the observation. Totally 15 baselines were observed, four of them are repeat-baseline.

Table 1: GPS surveying's basic technical requirements

Synchronous observation time (min)	Data sampling intervals	Total effective satellite observation number	Repeat measuring baseline percentage (%)	Satellite height angle(*)	PDOP	The average repeat station	
≥90	≥15	≥5	≥5	≥15	≤6	≤2	

According to the official standards GB50026-93 on engineering survey, height network was built as a closed –loop for the level instrument. This Swedish WILDNA2 high precision level instrument is well equipped by parallel light tubes and WILDGPLEZN indium steel rule. Three back-forward surveys were taken to meet the request of second order level accuracy. Length for a single trip is 320m.Totally 10 survey stations were involved. Differences in height for each observation is less than the allowed of +/- 0.95mm.

2.4.2 Vertical and horizontal Displacement monitoring

Vertical displacement was observed to meet the second order accuracy required for level survey. Together with the working base points, the WILD NA2 high precision level instrument and a 2.0m long indium steel rule were used to measure the monitoring target points. The deformation error in height was controlled under +/- 1mm. Moreover, horizontal displacement was observed using WILD T2 universal theodolite consisting of metal plate. A method of front cross for detecting ground deformation was applied to monitor the horizontal displacement for target points. Since, the reference nets is fabulous and will not be blurred by the light refraction. Based on independent plane coordinates obtained in different period of survey for the fame target, it can define the horizontal displacement (△;11).

If the first observed plane coordinates for target point is X1, Y1 and the second observed plane coordinates for this same target point is X2, Y2, the horizontal displacement △;ii and the direction of the displacement (&), it can be derived from the equations given below:

$$\Delta_i = \sqrt{\left[(X_2 - X_1)^2 + (Y_2 - Y_1)^2\right]} \quad \text{..........(Eq. 1)}$$

$$A_i = \arctan\left[\frac{(Y_2 - Y_1)}{(X_2 - X_1)}\right] \quad \text{..................(Eq. 2)}$$

The observation period depends on the construction progress. Usually, it defined 1-5 days as one period and totally 32 periods were involved in the study.

2.4.3. Incline deformation monitoring of foundation pit by Inclinometer

APVC plastic tube with diameter of Q70 mm and a cross "+" inside was insert to the soil outside the pot wall dour the measurement of the incline deformation. To ensure the effects of the measurement, a depth of about ~20-25m is appropriate for the tube to be planted. CX-01 inclinometer was used to observe every 0.5m form 0~180 degree twice for each monitoring. The survey accuracy is<+/-1.0mm.

3. Results and Discussions

3.1 Data processing of GPS Baseline Network

In this study, professional software produced by United States manufacturer in data processing has been used. The GPS station mark network measurement closing error test is divided into synchronous ring test. These two rings (coordinates and variance components) closing error should be zero in the theoretical way. But due to various observational and data processing model error, the value is generally not zero. The closing error of synchronous ring coordinates variance components meets the following requirements and depicts as equations discussed below.

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$$W_x \le \frac{\sqrt{n}}{5}\sigma,\ W_y \le \frac{\sqrt{n}}{5}\sigma,\ W_z \le \frac{\sqrt{n}}{5}\sigma \ \ldots\ldots\text{(eq. 4)}$$

$$W=\sqrt{W_x^2+W_y^2+W_z^2} \le \frac{\sqrt{3n}}{5}\sigma \ \ldots\ldots\ldots\text{(eq. 5)}$$

The closing error of asynchronous ring coordinates variance components meets following requirements:

$$W_x \le 2\sqrt{n}\sigma,\ W_y \le 2\sqrt{n}\sigma,\ W_z \le 2\sqrt{n}\sigma \ \ldots\ldots\ldots\ldots\text{(eq. 6)}$$

Where, n—: edges number in closed ring; σ—:corresponding level of precision

After the completion of baseline vector loop closing error's test, it has to be continue to the GPS control network unfettered free network adjustment, and then processed unconstrained adjustment in WGS-84 coordinates. Adjustment control parameters set as default to test field observation outcome's accuracy of internal consistency.

All baseline vectors in control network take part in adjustments. The adjustment first weighted in proportion factor, then success- fully through iterative calculating process without obvious gross error, chi-square test passed. Also, all observation outcomes pass test, none unusual events occur. The observational results have a qualified internal accuracy. The baseline solution have a effectively fixed solution, the solution's maximum error of +/- mm, the minimum of +/-2 mm , passed the inspection of synchronous ring. Measurement results are found to be reliable.

3.2 Observation Data Analysis of Deep Horizontal Displacement for the Soil around the Foundation Pit

The maximum deep soil displacement of 29.74 mm for Q1# had been observed since the soil was removed from the foundation pit until it was put back to the box culvert. The situation about Q2 #cannot reflect from our data since the upper side of 3m of the No. Q2# hole was ruined during the construction. The maximum horizontal displacements for Q1#, Q2# and Q4# were all over the warning value of 3 mm/day once. It immediately informed the construction company for improvement strategy and finally made the horizontal displacements of these holes under control and ensured a safe and steady construction later on.

3.3 GPS Data Analysis for Arch Deformation

The maximum arch displacement was summed up to 21cm. As shown in enclosed figure 1, this large displacement makes the steel arch in the shape of I deformed. After it warned the construction company of the situation, the modified arch in the shape of H worked well. The maximum vertical displacement is 3.4mm for W2 point due to the horizontal displacement. This influence is normal though. During the excavation and construction of the foundation pit, the horizontal displacements of both arch and soil were the warning value for several times. Fortunately, it finally worked together with other professionals like designers, inspectors and engineers to ensure the construction accomplished well.

4. Conclusions

In this study, GPS measuring technology has been used because of several advantages such as high measuring accuracy and no restrictions for measuring visibility conditions. When foundation pit health monitoring is run by the deformation monitoring method combined with traditional and modern GPS measuring techniques, the following points should be taken into the considerations:

1) When establishing a datum mark network, each location of datum marks should meet the relevant technical requirements of GPS measuring and the follow-up monitoring methods. One datum mark should be visible with at least another one, and should act as a reference point at the meantime. It would be even better if a datum mark maintains visibility with a number of datum marks to check measurements of distances and angles during the deformation point monitoring.
2) In urban GPS baseline measuring, baseline observation time should be adjusted with the building conditions. When the datum marks at baseline ends has a small elevation with the sky obstructions, the baseline observation time should last for 30 to 60 minutes; when the large, the observation time should be extended; when the elevation is more than 45°, then the observation time should be no less than 90 minutes.
3) When deformation reaches the warning value, person should figure out the tendency for the alternative displacement of the foundation pit by considering the construction situation and analyzing the observation data. All the professionals should work together to modify the schedule and strategy of construction according to the correct information derived from our monitoring. In this way, the construction would be processed in a safe environment.

The results of this practice indicate that GPS technique, which possesses many advantages that traditional survey technique lacks, is very advantageous at monitoring the deformation of foundation pit in the engineering world. The reliable information and constructive suggestions for combining this modern technique with traditional survey method can ensure the project to be accomplished safety. Engineering construction industry in the near future will surely benefit from the GPS instruments through their continuous development, cheaper costs, rich computational models and fantastic functions.

Conflict of Interest: There is no conflict of interest between the authors

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