Influences of GPS Point Coordinate Selection on Metro Intersection Area Control Network

Yiteng Xu1,2, Peirong Deng4, Rongli Wang1,2, Zhifa Yu1,2, Lixin Li1,2, Hewen Liu1,2, Feng Xu3

1 Tianjin Port Engineering Institute Ltd. of CCCC First Harbor Engineering Company Ltd., Key Laboratory of Geotechnical Engineering, Ministry of Communications, Key Laboratory of Geotechnical Engineering of Tianjin, Tianjin 300222, China;
2 CCCC First Harbor Engineering Co., Ltd., Tianjin 300461, China;
3 China Railway Liuyuan Group Co., Ltd., Tianjin 300308, China;
4 Xianyang vocational and technical college, Xixian New Area 712000, China;

Corresponding author’s e-mail: 18710804642@163.com

Abstract. At present, there are more and more crossover interchange nodes in Metro lines. The selection of coordinates of overlapping GPS control points is the key to the layout of control networks in the extension and intersection areas of Metro lines. The selection of GPS point coordinates directly affects the overall adjustment results of the control network, and further affects the measurement and monitoring work during the follow-up construction and operation. According to the actual engineering case, the influence of different starting coordinates of GPS points in the cross region on the results of precision conductor points was systematically analyzed and studied, then summarize the problems in the above cases, and the corresponding solutions are given. Finally, the systematic solutions are summarized for the similar projects currently common in China.

1. Foreword

The subway engineering plane control network is the basis of various measurement work in engineering construction. The accuracy of the control network directly determines whether the geometric position of the structure is accurate and the quality of the line [1-2]. The subway engineering plane control network consists of two parts. The first-level control network is the GPS control network, and the secondary control network is the precision traverse control network, and the control network is arranged step by step [3-5]. The plane control network of subway engineering is arranged independently along the line according to the sequence of construction of each line in the subway planning network [6]. In the cross area of subway lines, the new network layout must be connected to two or more GPS control points of the old network [7-8].

Before the GPS control network is measured, according to the planning and design of subway line, relevant data such as the existing urban control network along the line and the marking and accuracy of subway should be collected and analyzed [9]. At present, there are more and more cross-transfer nodes in the subway line. In the extension and cross-section of the subway line, how to select the coordinates of the GPS control points is the focus of the control network deployment [10]. The selection of GPS point coordinates directly affects the coordinate results of precise traverse points [11].
According to the measurement data of a project, the influence of different line coordinates on the precision traverse point is analyzed, and the solution is given.

2. Project example

2.1. Project summary

The length of the A project line is about 14.123km, of which the I section is about 11.375km long and the II section is about 2.748km long. There are 8 stations in the line, of which 3 are interchange stations. In order to ensure the connection of lines and eliminate the construction errors caused by the system differences of different line control networks, the old line and the line under construction have better smoothness. When the control network of A project is laid, the GPS points of B project M3G32, M3G34, M3G35, M3G36, DX29 and DX109A are jointly measured.

The comparative analysis between the results of project A GPS control network and the results of project B control network shows that the coordinates of the coincidence points are less than the tolerance requirements of 25mm for the coincidence points coordinates of different line control points specified by Code of measurement for urban rail transit engineering (GB 50308-2008). Considering the need of engineering construction, the construction unit of A proposes to adopt the coordinates of control points of overlapping new network results. The B engineering GPS control network was deployed and implemented in 2014. In 2016, the A project and the B project started construction at the same time. Due to the serious damage of the B engineering control network, the A -project precision traverse points DX21, DX32, DX33 and DX34 were jointly tested in the first test of the B project in 2016.

There are 10 coincidence points between A project and B engineering line, including 4 GPS points (M3G32, M3G34, M3G35, M3G36) and 6 precision traverse points (DX29, DX21, DX32, DX33, DX34, DX109A).

2.2. Problem analysis

Project B was originally planned to start construction in 2014, and the A project started construction in 2016, and the A project was connected to the GPS point of the B project in the control network. In the construction, the two line control networks meet the construction needs of each line. However, in the actual civil construction, in 2016, the construction of A and B projects at the same time, there is a cross-operation area. In the preliminary preparation of the cross-regional project, the B project construction unit has carried out a control point handover pile, and the subsequent A project construction unit has once again conducted a control point handover pile for the same construction unit. Due to the early coordinate selection of GPS points in the control network, the control points of the AB project overlap in the intersection area, but the duplicate points are not co-coordinates, that is, the same construction unit has two sets of coordinates at the same control point in the construction of the two lines. The coordinates of the 10 coincident control points in the AB project are compared as follows:

| Serial number | NO.      | Difference (mm) | Remarks                  |
|---------------|----------|-----------------|--------------------------|
| 1             | M3G32    | 19.8            | -4.4                     |
| 2             | M3G34    | 16.4            | 3.3                      |
| 3             | M3G35    | 21.0            | 10.4                     |
| 4             | M3G36    | 14.7            | 3.5                      |
| 5             | DX29     | 16.0            | 4.6                      |
| 6             | DX21     | 20.3            | 6.0                      |
| 7             | DX32     | 30.3            | 14.9                     |
| 8             | DX33     | 23.8            | 14.1                     |
| 9             | DX34     | 19.0            | 3.6                      |
| 10            | DX109A   | 15.8            | 6.6                      |
From the difference of coordinates in the above table, it can be seen that the difference of coordinates between coinciding GPS points is less than 25 mm, but the difference of coordinates between coinciding precise traverse points is larger because of the selection of coordinates of GPS points. The maximum difference of coordinates is DX32 (X is 30.3 mm, Y is 14.9 mm), which seriously affects the subsequent engineering construction. How to select the intersection control points becomes an urgent problem to be solved.

2.3. Problem analysis
Based on the comparative analysis of the shape of the crossing area and the coordinates of the coincidence control points, two schemes are proposed to solve the above problems.

2.3.1. The first method
(1) Specific operation
Considering that the project B control network was set up in 2014, the A project is the late construction, and the B project is jointly tested. Therefore, it is recommended that the results of the B engineering control network remain unchanged. The A project will use the coordinates results of the B engineering control network for the four GPS points M3G32, M3G34, M3G35, and M3G36 in the intersection area. Recalculate the results of the A engineering control network and compare and analyze the results of the cross-regional control network. The coordinates of coincidence control points of A B project are compared as follows:

| Serial number | NO.     | Difference (mm) | Remarks         |
|---------------|---------|-----------------|-----------------|
|               |         | X    | Y    |                             |
| 1             | DX29    | -1.3 | 1.9  | Overlapping                 |
| 2             | DX21    | 0.2  | 2.0  |                               |
| 3             | DX32    | 0.9  | 1.4  | point of intersection        |
| 4             | DX33    | -0.6 | 1.6  | area in AB                   |
| 5             | DX34    | 0.8  | -0.4 |                               |
| 6             | DX109A  | 0.3  | 0.3  |                               |

From the analysis of the coordinates difference of the above table, it can be known that the coordinates of DX29, DX109A, DX21, DX32, DX33 and DX34 of the precision wire control points change greatly after the A project uses the results of the B engineering control network in the coordinates of the four GPS points in the intersection. Compared with the coordinates of B project, the difference is very small. The maximum difference point of coordinates is DX21 (X is 0.2mm, Y is 2.0mm). It can be seen that the selection of GPS coordinates directly affects the coordinate results of precise traverse points.

(2) Method advantages
After using the B engineering coordinate results in the GPS coordinates of the A project in the intersection area, the coordinate difference of the control points of the intersection area can be better eliminated. When the coordinates difference of precise traverse points is less than 12 mm, the whole achievement of precise traverse points directly adopts the same point coordinates of B project in the cross area. This scheme not only avoids the trouble caused by using two sets of coordinates in construction, but also avoids the management confusion caused by the two sets of coordinates. The most important thing is to ensure the measurement accuracy of the cross area.

(3) Method disadvantages
After the coordinates of the GPS points in the A project in the intersection area adopt the coordinates of project B, the adjustment calculation of the precision traverse control network will cause the coordinates of other precise traverse points around the GPS point to change. Therefore, with this method, the results of the A Engineering Control Network need to be recalculated and new results reports need to be submitted to increase the computational cost. At the same time, the construction
units in the change area of the whole control network need to re-transfer pile, and the additional workload of pile transfer will be increased.

2.3.2. The second method

(1) Specific operation
Project A and Project B respectively use the control points of their respective lines. Each unit manages the results of its own control network. The two sets of measurement results do not interfere with each other. Each unit completes its functions as required to ensure the smooth construction of the project.

(2) Method advantages
The azimuth of the control points in the intersection area between the A project and the B project is compared and analyzed, and the azimuth angle of the joint side does not exceed 12″. Using this coordinate to calculate the penetration error of adjacent intervals meets the requirements of specifications, and using any set of result coordinates alone can meet the needs of line accuracy. That is to say, the results of the control network using the respective lines by the construction units in the intersection area between the A project and the B project can theoretically ensure better penetration of the lines. The comparison table of azimuth angles of joining edges is as follows:

| Serial number | Line NO. | Azimuth | Azimuth difference (″) |
|---------------|----------|---------|------------------------|
| 1             | M3G32    | 322°59′23.25″ | 0.84 |
| 3             | M3G34    | 322°59′22.41″ | |
| 7             | M3G32    | 322°59′23.25″ | 0.84 |
| 3             | M3G34    | 322°59′22.41″ | |
| 7             | DX29     | 355°30′11.10″ | 1.17 |
| 2             | M3G34    | 355°30′30.27″ | 1.17 |
| 3             | DX29     | 355°30′30.27″ | 1.17 |
| 7             | DX109A   | 342°56′40.38″ | -1.6 |
| 3             | M3G36    | 342°56′41.98″ | -1.6 |
| 7             | M3G35    | 304°10′10.11″ | -1.32 |
| 4             | M3G36    | 304°10′11.43″ | -1.32 |
| 3             | DX23     | 114°27′1.61″   | 5.37 |
| 5             | M3G36    | 114°26′56.24″ | 5.37 |
| 3             | DX23     | 114°26′56.24″ | 5.37 |

(3) Method disadvantages
Despite the technical explanation, the two coordinates are easily confused in the actual use of station foundation pit excavation, main body construction, shield tunnelling, track laying and alignment, causing trouble.

2.3.3. The using method
Based on the comparative analysis of the above two methods, considering that most of the A projects are located within the scope of the B project, combined with the overall planning of urban rail transit in the city, as well as the specific implementation and operation of the site, the A engineering construction unit recommends the first method.
3. Similar engineering problems
The above-mentioned cases only focus on the analysis and study of transfer coordinates of a project A and a project B at a station. However, in the current subway lines built in many cities, especially in the construction of urban subway ring line, there are many transfer stations and complex influencing factors.

Xi’an Metro Line 8 is the first ring subway in Xi’an, with 35 stations in total, of which 17 are transfer stations. Guangzhou Metro Line 11 is the first ring subway in Guangzhou. There are 32 stations in the line, of which 21 are interchange stations. Chengdu metro line 7 is the first circular subway in Chengdu, with 31 stations and 22 transfer stations. The world’s longest underground subway line, Beijing Metro Line 10, has a total of 45 stations, including 24 interchange stations. There are many transfer stations in the above-mentioned ring subway lines. In the layout of the ring subway control network and the layout control of the ring line subway transfer line, the coordinates of the GPS control points in the intersection area will also face greater challenges. According to the characteristics of the current subway construction, combined with the actual engineering case, the data of the built subway control network is compared and analyzed, and the scheme of selecting the GPS control point coordinates in the intersection area is given.

3.1. Option One
When the coordinates of the GPS control point of the new line control network in the intersection area and the GPS control point of the old line control network are less than the tolerance requirement of the difference of the coordinates of the coincidence point of the different line control points of the Code of measurement for urban rail transit engineering (GB 50308-2008) specified by less than 25mm. When the transfer project is constructed at the same time and the transfer station form is the same station four-line transfer. The coordinates of the GPS control point of the new line control network in the intersection area adopt the old results, that is, the new line adopts the old result and the old line adopts the old result too. It can better guarantee the quality of engineering connection and is convenient for surveyors to use during construction.

3.2. Option Two
When the coordinates of the GPS control point of the new line control network in the intersection area and the GPS control point coordinates of the old line control network are less than the specification tolerance requirements. When the transfer project is constructed in different periods and the transfer station is not the same platform transfer, the coordinates of GPS control points of the new line control network in the crossing area adopt new achievements. This means that the new line adopts new results, the old line adopts the old results, and the two sets of coordinates in the intersecting area are parallel, which can better ensure the quality of the line and the smoothness of the line, it is convenient to carry out the work of laying track and adjusting line and operation monitoring.

3.3. Option Three
When the coordinates of the GPS control point of the new line control network in the intersection area and the GPS control point coordinates of the old line control network are greater than the specification tolerance requirements, it shows that the GPS point displacement occurs in the intersection area. Then the coordinates of the GPS control points of the new and old line control network in the intersection area adopt new results. This means that new achievements are adopted in the new line and new achievements are adopted in the old line. The owner unit shall make technical submissions to the relevant units of the old line, and clarify that the GPS point coordinates in the intersection area change and the new coordinates shall be adopted. In this way, not only the coordinates of old lines can be updated in time to ensure the smooth construction of old lines, but also the construction accuracy of new lines can be better guaranteed.
4. Conclusion
No matter the transfer between the line under construction and the existing line, or the co-construction of the line under construction and the transfer line, no matter the intersection of the two lines, or the intersection of the ring line and the multiple lines. The selection of control points coordinates of intersecting areas in the layout of the circuit control network must be paid enough attention and thought. In the early stage of control network layout data collection, control network shape design, coordinate comparison and analysis should fully consider the impact on the later stage of engineering construction. Combined with the structural form of the transfer station, considering the influence conditions, the degree of influence of the control network coordinate results on the station and the shield interval is judged. Comprehensively prepare the control network results report and submit the transfer pile information. It is avoided that the precision of the precise traverse point coordinates is poor due to the improper selection of the control points of the line intersection area, which in turn affects the construction of the project and the inconvenience of construction measurement and monitoring. Practice has proved that by adopting the above scheme, many problems faced in the current subway engineering control network deployment work can be better solved.

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