高速铁路 CPIII平面控制网的优化设计

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摘　要：采用模拟优化设计方法，对 CPIII平面网的点位精度、相对点位精度和可靠性指标进行了分析，结果表明：标准CPIII平面网测量方案的可靠性指标较差，为此，提出了 CPIII平面网的优化方案，采用本方案可减少 CPIII网的复测次数。

关键词：CPIII平面网；点位精度；可靠性指标；优化设计；无碴轨道

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高速铁路要求必须具备精确的几何线形参数，故对测量精度要求极高，为此一般布设CPIII平面控制网，且需要多次对 CPIII平面控制网进行复测。本文针对CPIII网的相对定位精度要求，采用模拟法对 CPIII网的精度指标进行了计算，推算了 CPIII网 2 次测量坐标较差的合理允许误差，并针对标准 CPIII网的可靠性指标很差的问题，对 CPIII网的可靠性指标进行了分析，提出了具有高可靠性的 CPIII网优化方案，以减少复测次数。

1　CPIII平面控制网网形结构

无碴轨道对线下基础工程的工后沉降要求非常严格，CPIII控制网测量还应等到线下工程沉降和变形满足要求，且无碴轨道铺设条件评估通过后进行。

1）区段沉降变形观测评估通过。2）桥梁防撞墙和路基接触网杆基础完成。3）精测网复测完成，复测报告评审通过。4）CPIII测量技术方案报批通过。5）CPⅡ加密点和 CPIII标志预埋完成。

1.1　CPIII控制点的布设

CPIII控制网是一种自由测站的特殊边角网，起闭于 CPⅠ或 CPⅡ 控制点上（见图 1），CPIII网控制点对称布设于线路两侧。

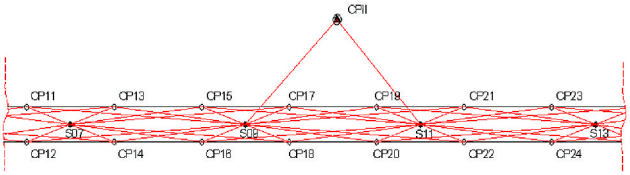

图 1　CPIII网标准测量方案

CPIII网一般采用测站间距为 120 m 的标准测量方案（见图 1），每个 CPIII点至少有 3 个方向；另有采用自由测站间距为 60 m 的改进测量方案一（见图 2），每个 CPIII点至少有 4 个方向。

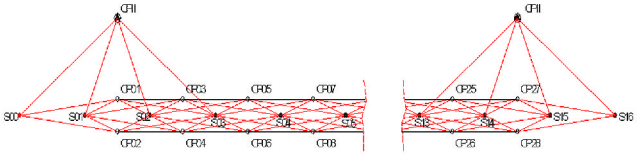

图 2　CPIII网改进测量方案一

以铁路中线方向为 Y 轴，垂直于铁路中线为 X 轴。

要求CPIII网点间的相邻点位的横向相对误差小于 1 mm，这一指标对于线路高平顺性至关重要。

2　精度和可靠性因子计算数学模型

由于 CPIII平面网具有规则、对称的特点，又是一种特殊的边角网，给定 CPIII平面网的水平方向和距离先验中误差，可按照间接平差方法，估算 CPIII网的点位误差、相对点位误差、可靠性因子。

2.1　CPIII平面网的精度估计

设计矩阵为 $N = B^T PB$，根据最小二乘原理，其逆阵的对角线元素即为各坐标分量的协因数，协因数阵为 Q，即：

$$Q = N^{-1}, q_{ii} = diag(Q_{ii}) \tag{1}$$

因此，控制网中各点的点位误差估计值为：

$$m_{xi} = \sigma_0 \sqrt{q_{xixi}} \tag{2}$$

$$m_{yi} = \sigma_0 \sqrt{q_{yiyi}} \tag{3}$$

式中，σ_0 为验前单位权中误差。

坐标差的协因数阵为：

$$Q_{\Delta\Delta}^{ik} = \begin{bmatrix} q_{\Delta x\Delta x} & q_{\Delta x\Delta y} \\ q_{\Delta y\Delta x} & q_{\Delta y\Delta y} \end{bmatrix} = Q_{ii} + Q_{kk} - Q_{ik} - Q_{ki} \tag{4}$$

式中，$Q_{ii}, Q_{kk}, Q_{ik}, Q_{ki}$ 为坐标分量的协因数阵的 2 维子矩阵。

相对点位误差估计值为：

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$$m_{\Delta x_{ik}} = \sigma_0 \sqrt{q_{\Delta x \Delta x}} \quad (5)$$

$$m_{\Delta y_{ik}} = \sigma_0 \sqrt{q_{\Delta y \Delta y}} \quad (6)$$

2.2 CPIII平面网的重复测量坐标限差

若取 2 倍的中误差为允许误差，由点位误差可得到各点的重复测量坐标限差：

$$\Delta x_i = 2\sqrt{2} m_{xi} \quad (7)$$

$$\Delta y_i = 2\sqrt{2} m_{yi} \quad (8)$$

2.3 CPIII平面网的可靠性分析

观测值 r_i 的多余观测分量：

$$r_i = (Q_{TT} P)_{ii} \quad (9)$$

$$r = n - u = \sum_{i=1}^{n} r_i \quad (10)$$

式中，r 为整个网的多余观测数；r_i 可以反映 GPS 控制网发现观测值中粗差的能力，称为可靠性因子；n 为总观测值个数；u 为未知数个数。

控制网可靠性良好的标准应遵循以下原则：控制网观测值平均可靠性因子一般为 0.4~0.5，且可靠性因子的数值不应相差过大，最小可靠性因子应大于 0.2。

3 模拟计算

鉴于 CPⅡ控制点的间距为 800 m ～ 1 000 m，计算时取 CPⅡ控制点的间距为 780 m，CPⅢ平面网水平方向中误差为：$m_L = \pm 2''$，距离中误差为：$a = \pm 1\,\text{mm}$，$b = \pm 1 \times 10^{-6}$。

取CPⅢ平面网的先验中误差估算点位精度和可靠性指标。

3.1 标准 CPIII平面网测量方案结果

标准 CPⅢ平面网每个自由测站至较近的 2 个或 4 个 CPⅢ点的方向观测值可靠性因子小于 0.2，取部分典型方向观测值的可靠性因子 ri 列入表 1（测站间距 120 m）。

表 1 标准 CPIII平面网典型方向观测值的可靠性

起点	终点	ri
S11	CP15	0.72
S11	CP16	0.71
S11	CP17	0.65
S11	CP18	0.64
S11	CP19	0.11
S11	CP20	0.11
S11	CP21	0.11
S11	CP22	0.11
S11	CP23	0.67
S11	CP24	0.67
S11	CP25	0.76
S11	CP26	0.76

3.2 CPIII平面网改进测量方案一结果

改进 CPⅢ平面网每个自由测站至较近的 2 个或 4 个 CPⅢ点的方向观测值可靠性因子均较小，取部分典型方向观测值的可靠性因子 ri 列入表 2（测站间距 60 m）。

表 2 CPIII平面网改进测量方案一典型方向观测值的可靠性

起点	终点	ri
S03	CP01	0.69
S03	CP02	0.68
S03	CP03	0.25
S03	CP04	0.26
S03	CP05	0.26
S03	CP06	0.25
S03	CP07	0.62
S03	CP08	0.62

标准 CPⅢ平面网测量方案和 CPⅢ平面网改进测量方案一的横向误差、纵向误差的比较分别见图 3、图 4。

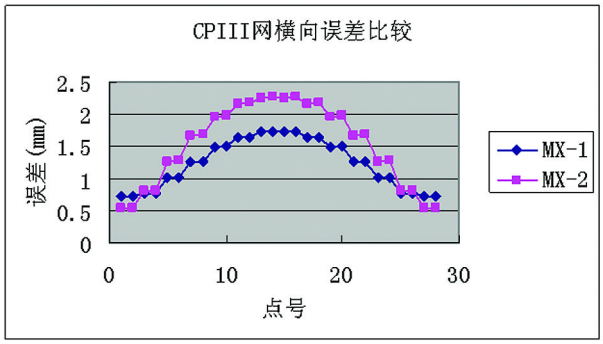

图 3 2 个方案的横向误差分布图

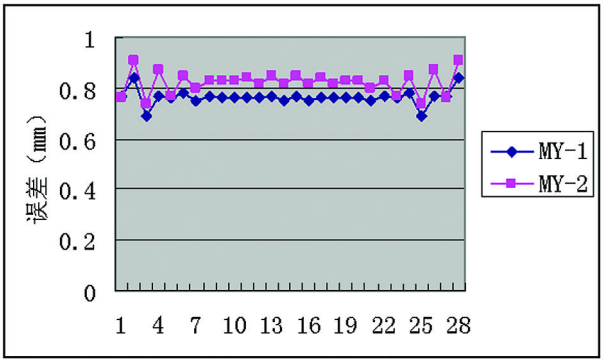

图 4 2 个方案的纵向误差分布图

横向误差明显比纵向误差大，最弱点位于 CPⅢ平面网的中间。

3.3 CPIII平面网改进测量方案二结果

在改进 CPⅢ平面网的基础上，每个自由测站观测前后各 3 对 CPⅢ点，此时网中每个 CPⅢ点至少有 5 个方向的边角交会，网中部的测站观测方向为 12 个，增加每个 CPⅢ点的交会方向将有利于提高可靠性指标（测站间距 60 m，CPⅢ点交会方向 5 个）。

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表 3　CPIII平面网改进测量方案二典型方向观测量的可靠性

起点	终点	ri
S03	CP01	0.74
S03	CP02	0.74
S03	CP03	0.31
S03	CP04	0.31
S03	CP05	0.31
S03	CP06	0.31
S03	CP07	0.78
S03	CP08	0.77
S03	CP09	0.80
S03	CP10	0.80

对比表 2、表 3 显见，CPIII平面网改进测量方案二的各个方向观测量可靠性因子均有不同程度的提高。3 个方案的精度、可靠性指标、费用指标详见表 4。

表 4　各个 CPIII平面网方案的技术、费用指标

技术指标	标准 CPIII 平面网	改进测量方案一	改进测量方案二
$m_{xi\text{-}max}$ / mm	1.73	2.28	1.31
$m_{yi\text{-}max}$ / mm	0.77	0.82	0.60
$r_{i\text{-}min}$（方向）	0.07	0.19	0.22
R ＜ 0.2 观测量（方向）个数	28	2	0
r_i（方向）均值	0.48	0.43	0.60
r_i（距离）均值	0.59	0.67	0.77
$r_{i\text{-}min}$（距离）	0.40	0.20	0.37
R ＜ 0.2 观测量（距离）个数	0	0	0
横向相对误差/ mm	0.7	0.7	0.5
纵向相对误差/ mm	0.8	0.7	0.6
方向观测量个数	86	120	172
距离观测量个数	86	120	172

从图 3、图 4 和表 4 可见，标准 CPIII平面网测量方案横向坐标误差小于 CPIII平面网改进测量方案一，其原因是改进 CPIII平面网的测站数较多，误差传播增大。2 种网形的 CPIII网点间的相邻点位的横向相对误差均小于 1 mm，符合《暂规》的要求，但由于标准 CPIII平面网测量方案的点交会方向数少于CPIII平面网改进测量方案一，标准 CPIII平面网有 28 个方向观测值的可靠性因子小于 0.2，CPIII平面网改进测量方案一的可靠性指标较好，对于CPIII平面网改进测量方案二，仅有 4 个水平方向观测值的可靠性因子在（0.2，0.3）区间内，其余均大于 0.3，平均可靠性因子为 0.68，说明CPIII平面网改进测量方案二的可靠性指标是最好的。

3 个方案的距离观测量的可靠性因子均较好，说明网的距离观测量的检核条件较多。

根据模拟计算结果，CPIII平面网改进测量方案二的点位精度较高，对于标准 CPIII平面网测量方案，根据式（7）、（8），若取 2 倍的中误差为允许误差，则 2 次测量坐标较差的允许值分别为Δx=4.9 mm，Δy=2.2 mm；同样，可计算 CPIII平面网改进测量方案一的 2 次测量坐标较差的允许值分别为Δx=6.4 mm，Δy=2.3 mm；CPIII平面网改进测量方案二的 2 次测量坐标较差的允许值分别为Δx=3.7 mm，Δy=1.7 mm。

从经济性方面分析，CPIII平面网改进测量方案二较 CPIII平面网改进测量方案一增加了 43%的工作量。

由于 CPIII平面网对无渣轨道施工的重要性，虽然CPIII平面网改进测量方案二的一次测量费用较大，但其点位精度和可靠性指标明显优于标准CPIII平面网测量方案和 CPIII平面网改进测量方案一，且采用此方案可适当减少 CPIII网的复测次数，为此，经综合考虑，将 CPIII平面网改进测量方案二作为优化设计方案。

4　结　语

3 种测量方案的 CPIII网点间的相邻点位的横向相对误差均小于 1 mm，由于标准 CPIII平面网的可靠性较弱，其可发现粗差的能力差，故采用标准 CPIII平面网测量方案是不利的，而 CPIII平面网改进测量方案二的可靠性指标最好，故 CPIII平面网的坐标成果的质量是可控的，采用改进测量方案二可适当减少 CPIII网的复测次数，2 次测量坐标较差的允许值应不大于 4 mm。

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distributed points as a cluster, and then extract the target point clouds.
Key words Density-based clustering algorithms, the density distribution of point cloud, noise remove (Page:101)

Method of Basic Geographical Information Module Implementation Based on Google Earth by YIN Qiang

Abstract This paper introduced the mentality and the implementation method of kinds application subsystem general modul redevelopment based on Googel Earth platform. It elaborated the implementation method of control and browse module and geographical information module, and implemented format conversion of the shp to kml file in the system.
Key words GE, basic geographical information modul, kml, format conversion (Page:105)

Establishment of the Geographical Name Inquiring System of Fuxin City Based on MO by REN Dongfeng

Abstract This paper talked about establishing the geographical name inquiring system of Fuxin city based on MapObjects controlling and VB language and in the foundation of the geographical name geodatabase of Fuxin city. The system achieved the function of brose, layers management, drawing, the geographical name inquiring, the buffer analysis, the shortest path analysis.
Key words geographical name inquiring system; system design;buffer analysis; path analysis (Page:107)

Formulas of Calculation of Road Horizontal Curve Coordinates in the Route Plane Control Survey Coordinate System by ZHEN Dengchun

Abstract A method of direct calculation of road horizontal curve coordinates in the route plane control survey coordinate system is introduced, and the related formulas, compact and practical, can be referenced for setting out of road horizontal curve, are derived.
Key words road;horizontal curve;coordinate calculation (Page:111)

Calculation and Application of Various Area in the Second Land Investigation by ZHANG Hui

Abstract This paper analyzed working method and mathematical models of line and sporadic feature, summary the advantages and disadvantages of various area proposed the improving and using direction, by Comparison between calculation formula of ellipsoid area and working method and precision assessment in the first land using status investigation.
Key words land investigation; area mature; precision assessment (Page:115)

Investigation about the Subdivision of the Digital Estate Figure of Wuhan by CHEN Zhen

Abstract The subdivision of the estate figure is apart of the plan of the real estate framing, and it's the basic figure of drawing and issuing the figure of the license of the estate. According to the provision of the property management at Wuhan, there are two ways of surveying and mapping the subdivision the figure. Framing is the basic unit of surveying and checking of the estate which is a very important code at surveying and management, and it is also the major index at the management of the records. The standardization of surveying and mapping the subdivision the estate figure is benefit for the department of the estate management, which can also support the service of the department. This thesis showed us some research about the surveying of boundary points, the coordination of the corner of the buildings, the serial number of the buildings and so on.
Key words the subdivision of the estate figure, express content, investigate of the technique (Page:118)

Role of Detection of Underground Pipeline in Municipal Engineering Design by XIAO Shun

Abstract Underground pipeline survey before carrying out municipal engineering is very important. This issue illustrated this significance by explaining the important role detailed municipal pipeline survey plays in municipal engineering, comparing between detailed municipal pipeline survey and underground pipeline survey and their pre- and follow-up services. Several illustrative cases were provided to enhance the conclusion.
Key words municipal engineering design, detailed municipal pipeline survey,detection of underground pipeline (Page:121)

Design and Analysis of the Deformation Monitoring Program about a Foundation Ditch in Chengdu by LI Yong

Abstract This paper summarized the foundation excavation monitor need pay attention to in the basic problems and general principles,and combining QingyangQu red east street in a Chengdu deformation observation projects,analyzed the project operation processes involved with some typical problems,including project profiles, benchmark layout,observation period and so on contents,and combined with actual situation corresponding conclusion.
Key words foundation ditch,benchmark,observation period (Page:125)

Optimum Design of CPIII Plane Control Network for High Speed Railway by XIAO Daiwen

Abstract By doing the simulation optimum design, the positional accurary,relative positional accurary and reliability of CPIII networks was analysed, and the result showed the reliability of CPIII network was bader. The optimum scheme of CPIII network was presented. And frequency of repeatable measurement of this CPIII network may was reduced.
Key words CPIII plane control network,positional accurary,reliability,optimum design,ballastless track (Page:127)

Thoughts of Surveying and Mapping Engineering Supervision by PENG Songlin

Abstract This paper starts with the analyzing the origin of relation and distinction of engineering supervision and project supervision, to discuss the need for the implementation of mapping and project supervision, and how could it be practiced. The focus is on how important the organization, legal system, market construction and other work are in promoting mapping and project supervision.
Key words supervision; engineering supervision of surveying and mapping;organization construction;legal system construction;market construction (Page:130)

Design and Practice of Deformation Monitoring of Building by FU Hai'ou

Abstract This paper expounded the design of the building's settlement monitoring process to Chengdu general tablet research building structural template Co., LTD as an example, the level of the stability analysis, combining results point on the watch for observation data statistics and analysis, and a detailed corresponding conclusion.
Key words subsidence monitoring,baseline point, stability (Page:133)

Application of Regession Analysis Model in Dam Deformation Monitor by YANG Yongchao

Abstract This article focused on a regression analysis to monitor dam

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