

Design of control network and survey for CSNS

Accelerator center of IHEP

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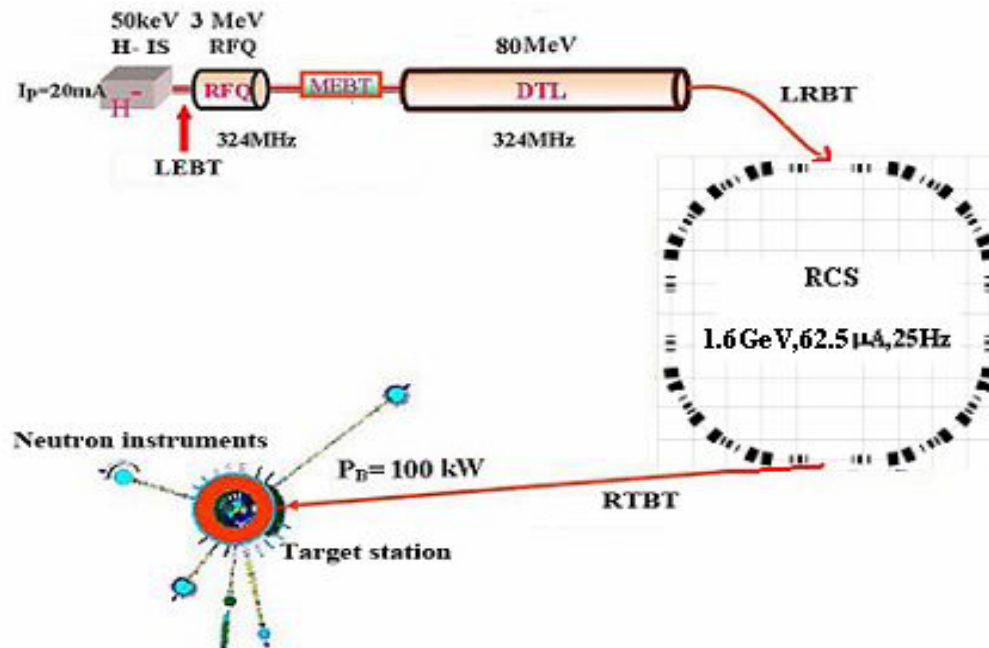
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1、 Project Overview

1.1 Brief introduction

China Spallation Neutron Source(CSNS) mainly consists of an H^- linac and a proton rapid cycling synchrotron. It is designed to accelerate proton beam pulses to 1.6 GeV kinetic energy at 25 Hz repetition rate, striking a solid metal target to produce spallation neutrons.



1.1 Brief introduction

As shown in Table 1, the accelerator is designed to deliver a beam power of 100 kW with the upgrade capability to 500 kW by raising the linac output energy and increasing the beam intensity.

Table 1 CSNS primary parameters in baseline	
Project phase	I
Beam ave. power, kW	100
Proton energy, GeV	1.6
Ave. current, I, μA	62.5
Repetition rate, Hz	25
Proton per pulse, 10^{13}	1.63
Pulse length, ns	<500
Linac energy, MeV	80
Linac peak current, mA	15
Target material	Tungsten
No. Moderators	3
No. neutron instruments	3



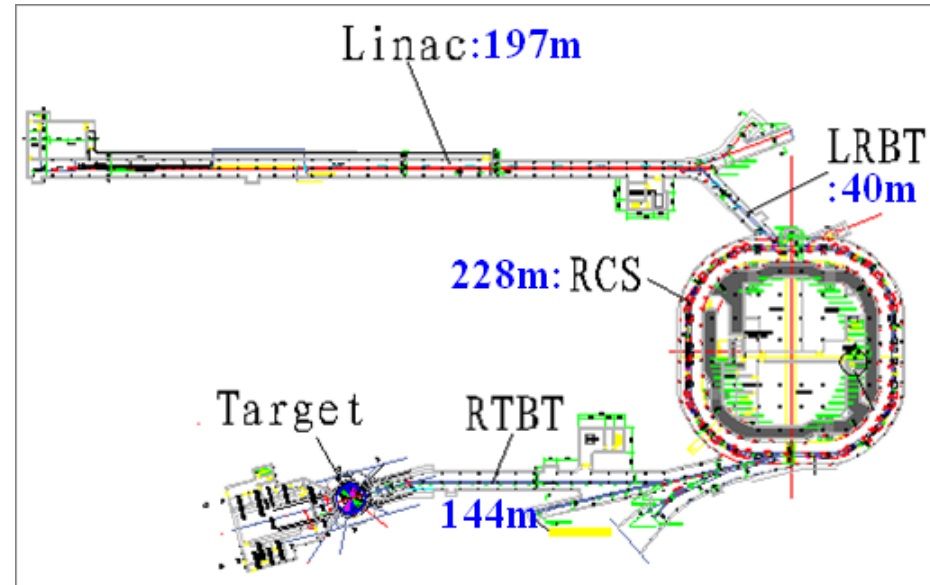
Linac

RCS

Spectrometer

1.2 General layout of CSNS

The length of the H- linac is about 197m, the circumference of the proton rapid cycling synchrotron(RCS) is about 228m, the length of the linac to RCS beam transport (LRBT) is about 40m, and length of the RCS to target transport(RTBT) is about 144m.



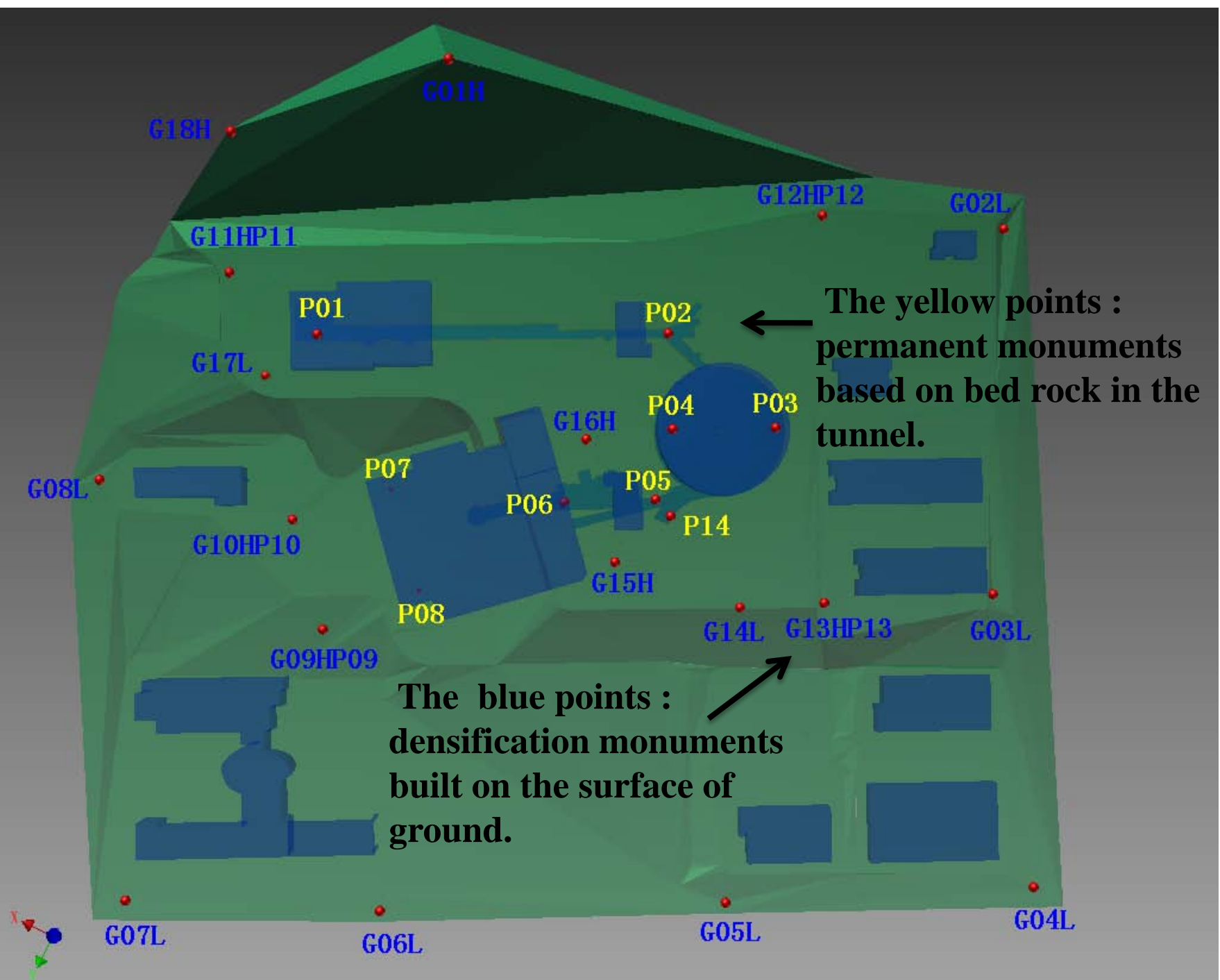
CSNS locates in Guangdong province, which is in the south of China . The construction of CSNS is in progress.

2、 Design of the primary network

2.1 Overall layout of primary network

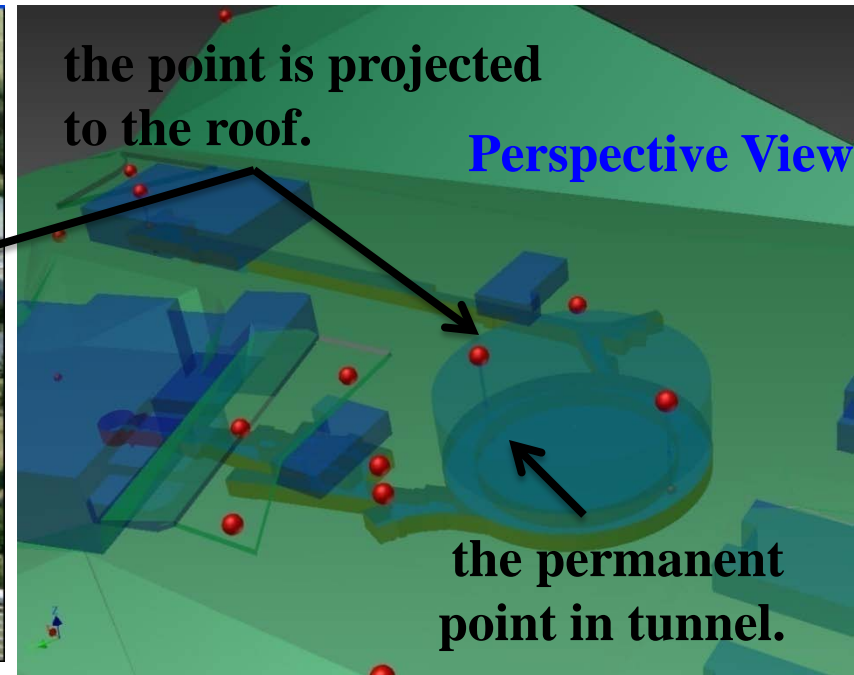
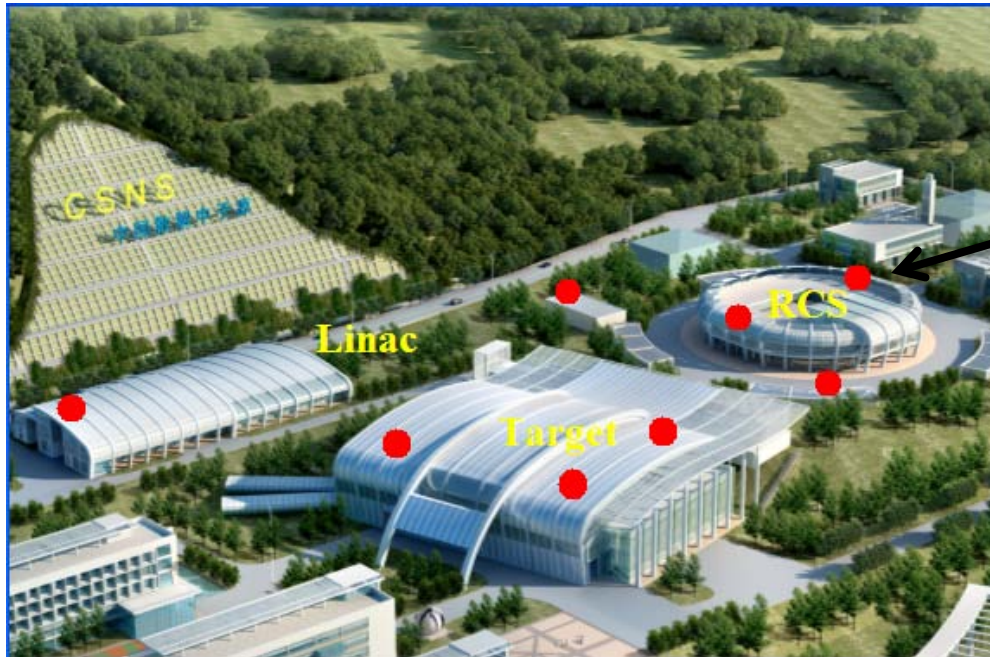
The control network of CSNS is classified into two grades: the primary network and the secondary network.

The primary network consists of 27 points, which is distributed over the whole area of CSNS. It is used for the layout of buildings and facility and to provide high accuracy control for the secondary network .



2.2 Characteristic of primary network

The permanent points in tunnel also belongs to the secondary control network, they can't directly connect with the other points on the ground. To carry out the survey, we should project them from tunnel to the roofs vertically. Wild NL nadir telescope will be considered for centering and projection.



3、 Survey scheme for the surface control network

3.1 Survey scheme for the surface network

In the early of the construction, the intervisibility between the control points can achieved easily, then we can use total station and leveling equipment to get the horizontal and vertical coordinates.

After the construction has been upbuilt, the buildings will cut the line of sight, it will be difficult to survey by total station.

A method is put forward to solve this problems.

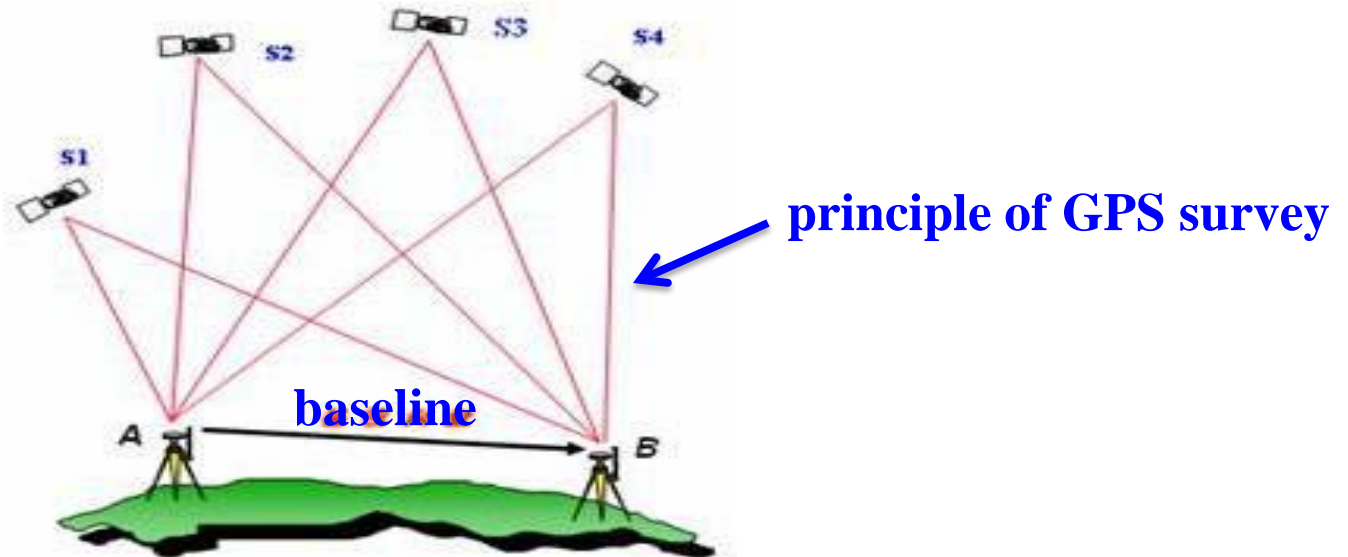
Horizontal survey: GPS and Total Station.

Height survey: spirit leveling and trigonometric leveling.

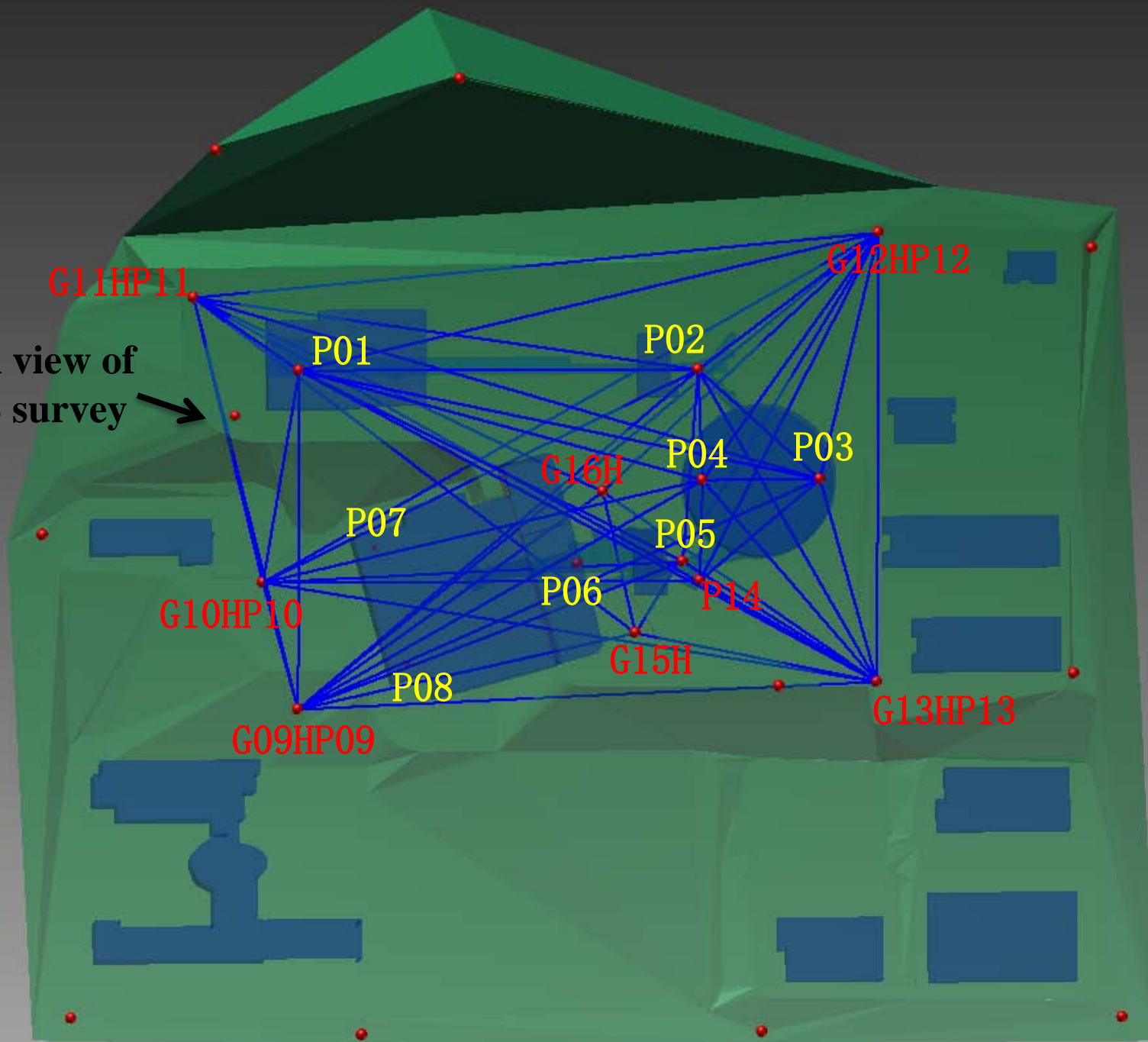
3.2 The method of horizontal survey

4 GPS receivers will be applied to measure the horizontal positions.

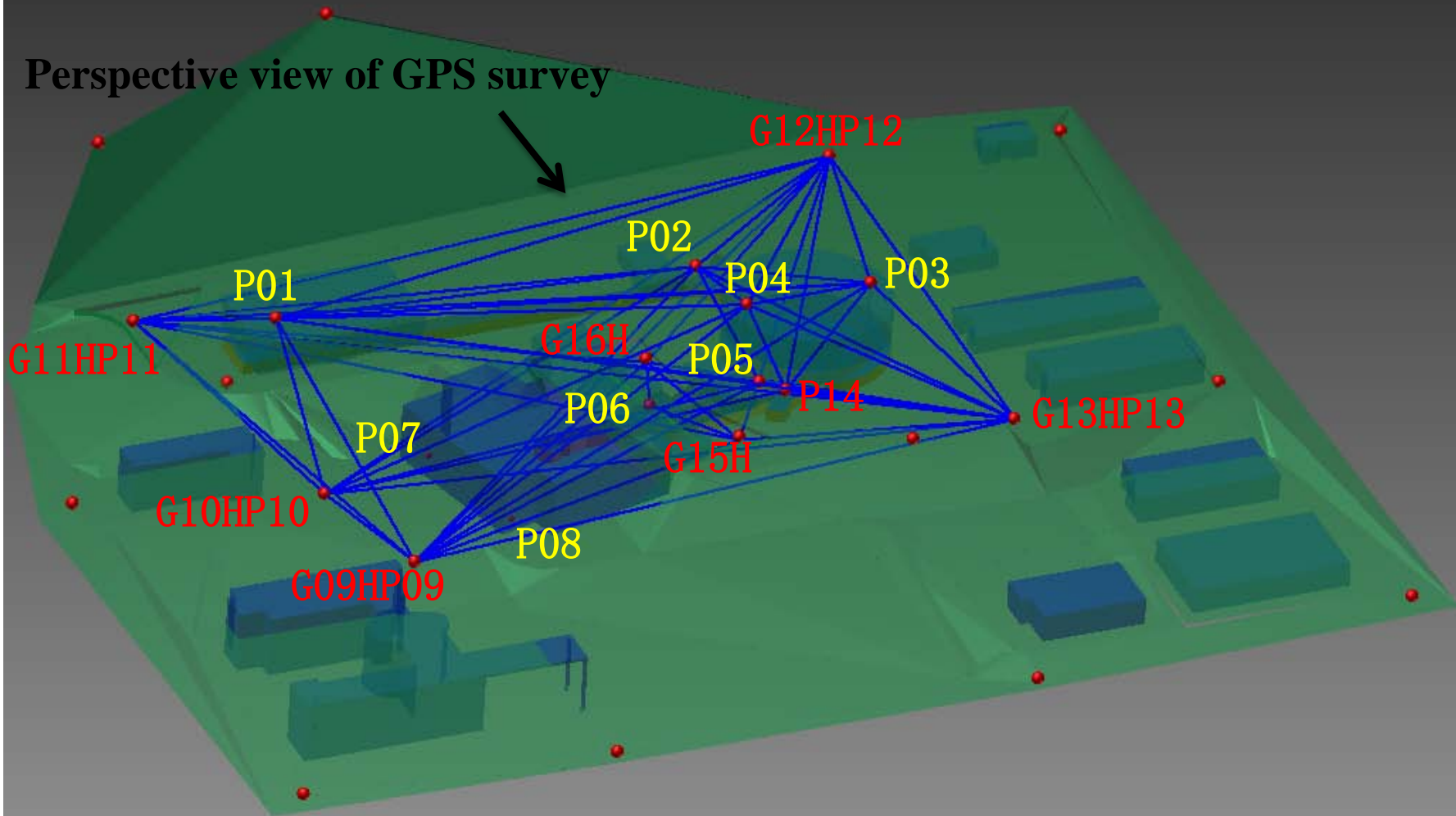
In each station, the GPS receivers are centered on every 4 monuments. With post-processing analysis, we can finally get the length of baselines between these primary control points.

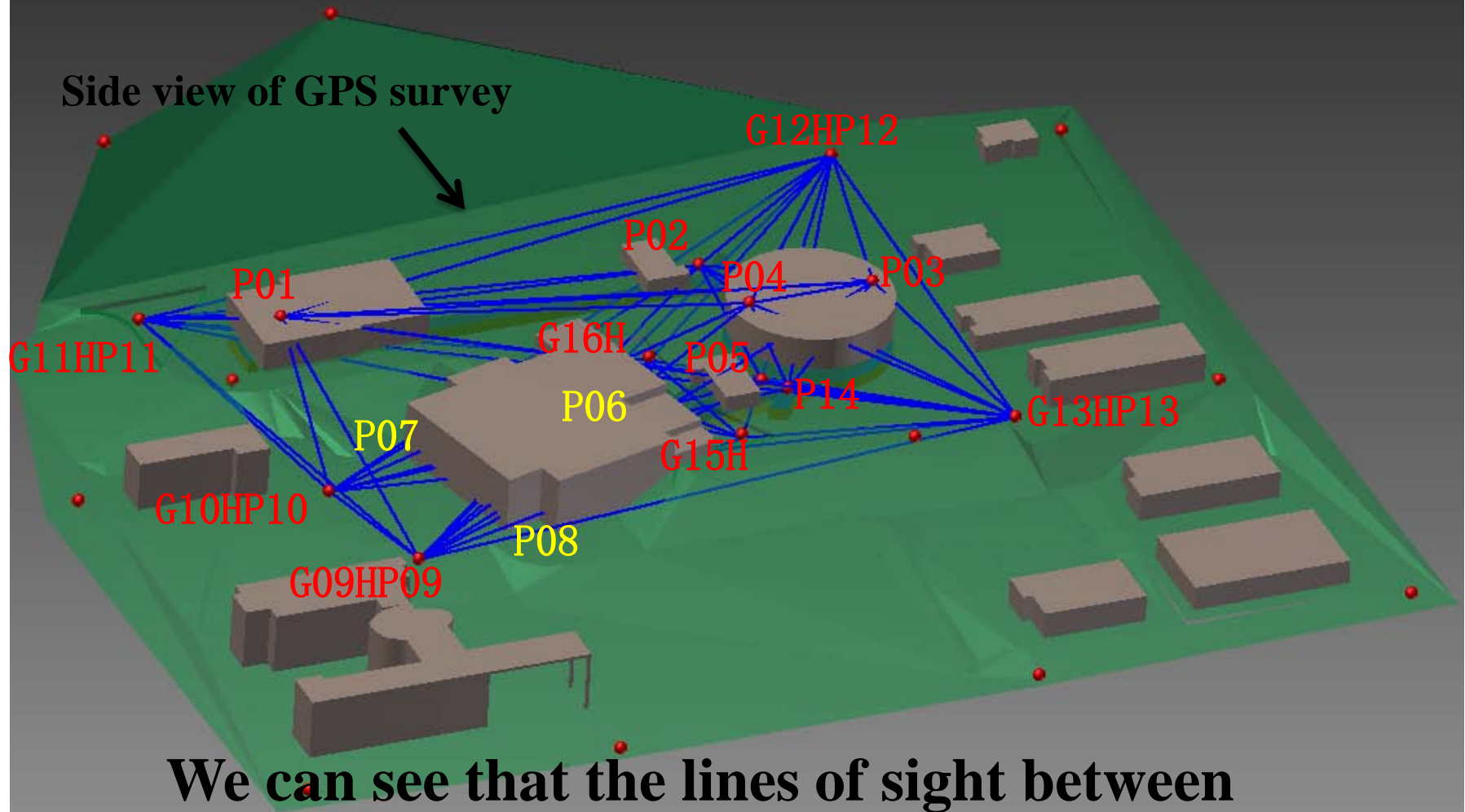


Plan view of
GPS survey →



Perspective view of GPS survey



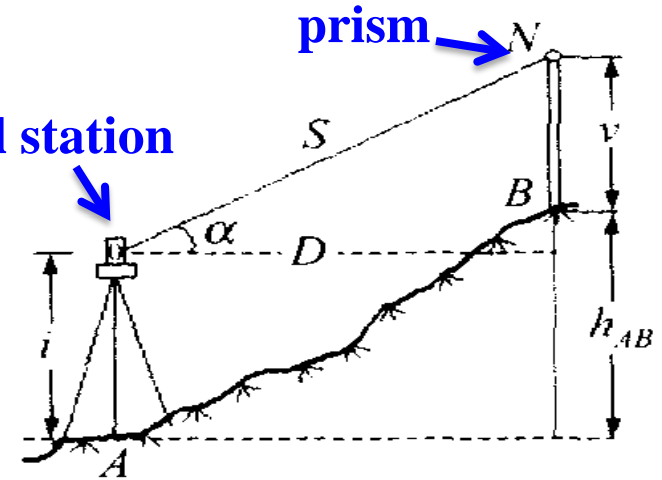


We can see that the lines of sight between points are cut off severely by the buildings. That's the reason why we apply GPS to carry out the horizontal survey.

3.3 The method of trigonometric leveling

Owing to its many advantages, trigonometric leveling has been more and more applied in many fields.

The basic concept of trigonometric leveling can be seen from fig1. When measuring the vertical angle and the slant distance S is used, then the precision elevation difference between A and B is therefore:



$$h_{AB} = D \cdot \tan \alpha + i - v + f$$

$$f = p + r = (1 - k) D^2 / (2R)$$

$$p = D^2 / (2R)$$

$$r = -k \cdot D^2 / (2R)$$

“R” - the average radius of earth.

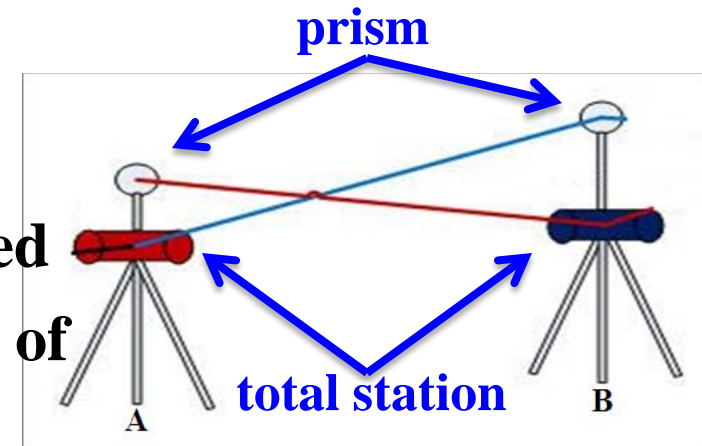
“f” - effect of earth curvature and refraction.

“p” - correction of earth's curvature.

“r” - correction of atmospheric refraction.

3.3 The method of trigonometric leveling

To eliminate the uncertainty in the curvature and refraction correction, vertical-angle observations are measured at two ends of the lines as close in point of time as possible.



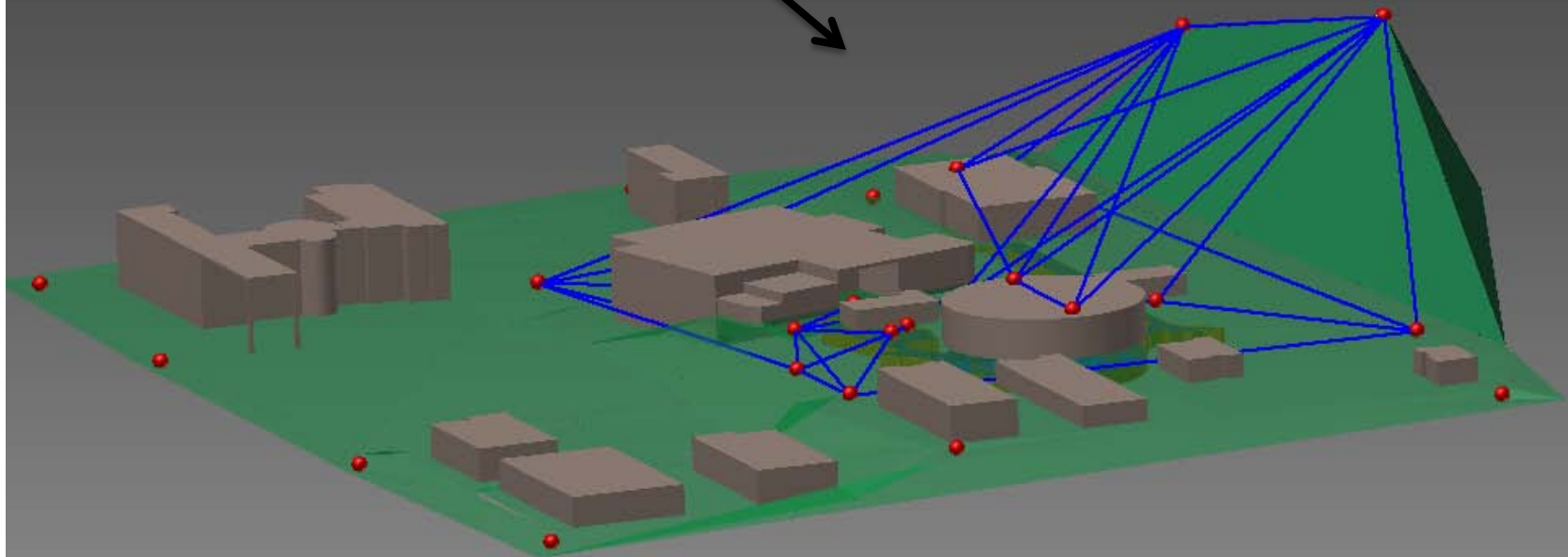
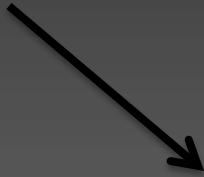
The correct difference in elevation between the two ends of the line is the mean of the two values computed by reciprocal observation. The formula are as follows:

$$\begin{cases} h_{AB} = D_{12} \cos \alpha_{12} + (1 - K_1) \frac{S_{12}^2}{2R} + i_1 - v_2 \\ h_{BA} = D_{21} \cos \alpha_{21} + (1 - K_2) \frac{S_{21}^2}{2R} + i_2 - v_1 \end{cases}$$

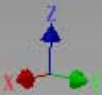
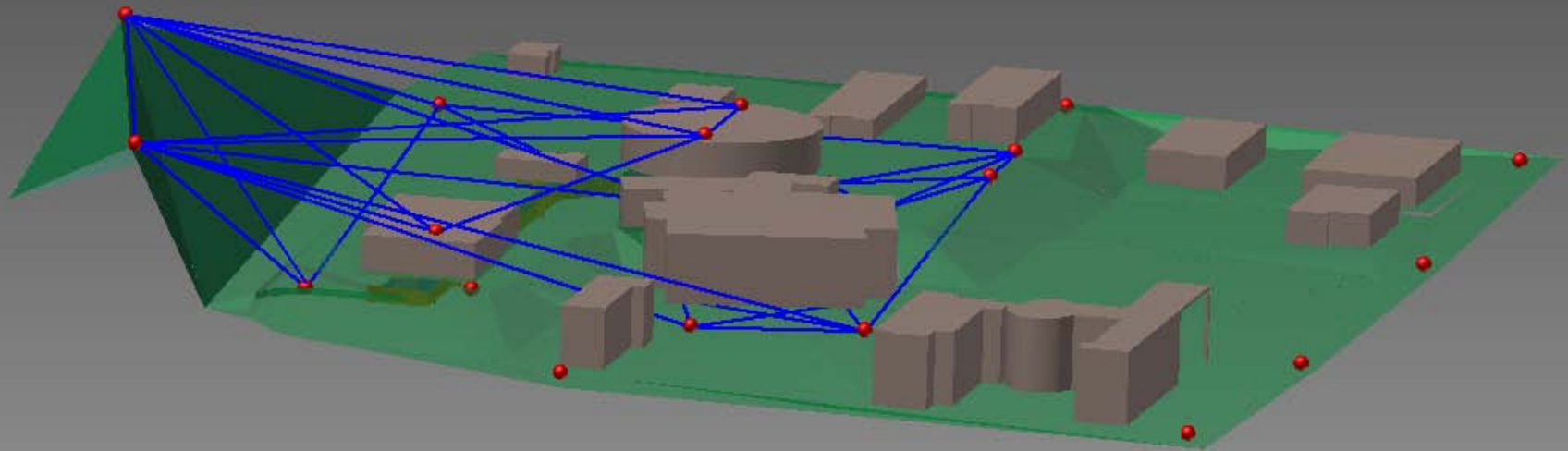


$$\begin{aligned} \overline{h_{AB}} &= \frac{1}{2} (D_{12} \cos \alpha_{12} - D_{21} \cos \alpha_{21}) \\ &\quad + \frac{1}{2} (i_1 - i_2) + \frac{1}{2} (v_1 - v_2) \end{aligned}$$

Side view of trigonometric leveling



Side view of trigonometric leveling



3.4 Automatic observation system based on Leica TDA5005

To improve efficiency and reduce the working strength, a automatic measurement program based on Leica TDA5005 total station is developed in Visual C++ 6.0 visualization development environment.

By sending ASCII orders through the serial communication between computer and the instrument, it finally realize to control the total station as we want.

With this program, it can easily for us to measure with total station.

Program debugging

Interface of the program

全站仪控制程序-IHEP准直测量

串口设置和状态

串口: COM4

波特率: 9600

校验位: NONE

数据位: 8

停止位: 1

关闭串口

STATUS: COM4 OPENED, 9600, N, 8, 1

自动测量

设站点号: A

照准点号: B

只获取角度

角度和距离

ATR 置零 测量 转盘

序号	类型	设站点号	照准点号	盘面	水平角(...)	天顶距(...)	斜距(m)	2C/测回差	2X/测回差	Sd/测回差	观测时间
测回1											
2	测量	FZ001	SG001	盘左	0.000020	94.552721	4.922132				2012-6-8
3	测量	FZ001	SG002	盘左	60.511673	96.114764	4.907432				2012-6-8
4	测量	FZ001	SG003	盘左	249.492821	91.300814	2.827518				2012-6-8
5	测量	FZ001	SG003	盘右	69.485655	268.301324	2.827318	-31.7	21.4	-0.2	2012-6-8
6				平均	249.491238	91.295745	2.827418				
7	测量	FZ001	SG002	盘右	240.510504	263.482186	4.907332	-11.7	9.5	-0.1	2012-6-8
8				平均	60.511089	96.114289	4.907382				
9	测量	FZ001	SG001	盘右	179.594834	265.044232	4.921932	-11.9	9.5	-0.2	2012-6-8
10				平均	-0.000573	94.552244	4.922032				
测回2											
12	测量	FZ001	SG001	盘左	359.595946	94.552775	4.922132				2012-6-8
13	测量	FZ001	SG002	盘左	60.511648	96.114782	4.907432				2012-6-8
14	测量	FZ001	SG003	盘左	249.492831	91.300826	2.827518				2012-6-8
15	测量	FZ001	SG003	盘右	69.485638	268.301345	2.827418	-31.9	21.7	-0.1	2012-6-8
16				平均	249.491235	91.295741	2.827468	0.0, 2, 1	0.0, 2, 1	0.1, 1, 2	
17	测量	FZ001	SG002	盘右	240.510567	263.482209	4.907332	-10.8	9.9	-0.1	2012-6-8
18				平均	60.511108	96.114286	4.907382	0.2, 1, 2	0.0, 2, 1	0.0, 1, 1	
19	测量	FZ001	SG001	盘右	179.594826	265.044205	4.922032	-11.2	9.8	-0.1	2012-6-8

测回测量

半自动测量

全自动测量

生成测前信息

生成测后信息

学习测量

测量中断继续

读取观测文件

观测数据检核

正在存储观测值, 仪器瞄准下一方向...

瞄准成功, 正在搜索目标...

目标已自动照准, 启动测量...

成功启动测量, 正在获取盘面信息...

盘面为右, 开始读取数据...

正在存储观测值, 仪器瞄准下一方向...

指令测量

**仪器指令参考:

\\仪器连接 R1Q, 111:1\r\n

\\开启ATR R1Q, 9018:1\r\n

\\搜索棱镜 R1Q, 9037:0.08, 0.08,

\\启动距离测量 R1Q, 2008:1, 1\r\n

\\获取距离数据 R1Q, 2108:3000, 1\r\n

\\正在转盘 R1Q, 9028:0, 0\r\n

\\获取盘面信息 R1Q, 2026:\r\n

\\停止测量 R1Q, 2008:0, 1\r\n

\\关闭仪器 R1Q, 112:0\r\n

手动发送指令 R1Q, 17017:3\r\n

%R1P, 0, 0:0

%R1P, 0, 0:0

%R1P, 0, 0:0

%R1P, 0, 0:0, 1

%

R1P, 0, 0:0, 4.203653011059765, 4.604285657

612372, 4.90733183359084

%R1P, 0, 0:0

%R1P, 0, 0:0

%R1P, 0, 0:0

%R1P, 0, 0:0, 1

%

R1P, 0, 0:0, 3.141535729371099, 4.626489937

15634, 4.922031928955377

计算器

角度 0

弧度 0

角度 0

角度 0

斜距 0

天顶距 0

角度转弧度

弧度转角度

相加

相减

计算

高差 0

平距 0

3.5 Simulation

Combined with the slant distance measured by GPS and the elevation difference measured by trigonometric leveling, we can calculate the horizontal distances between the monuments.

The precision of baseline is supposed to be about 1.5mm, and elevation difference precision is less than 2mm.

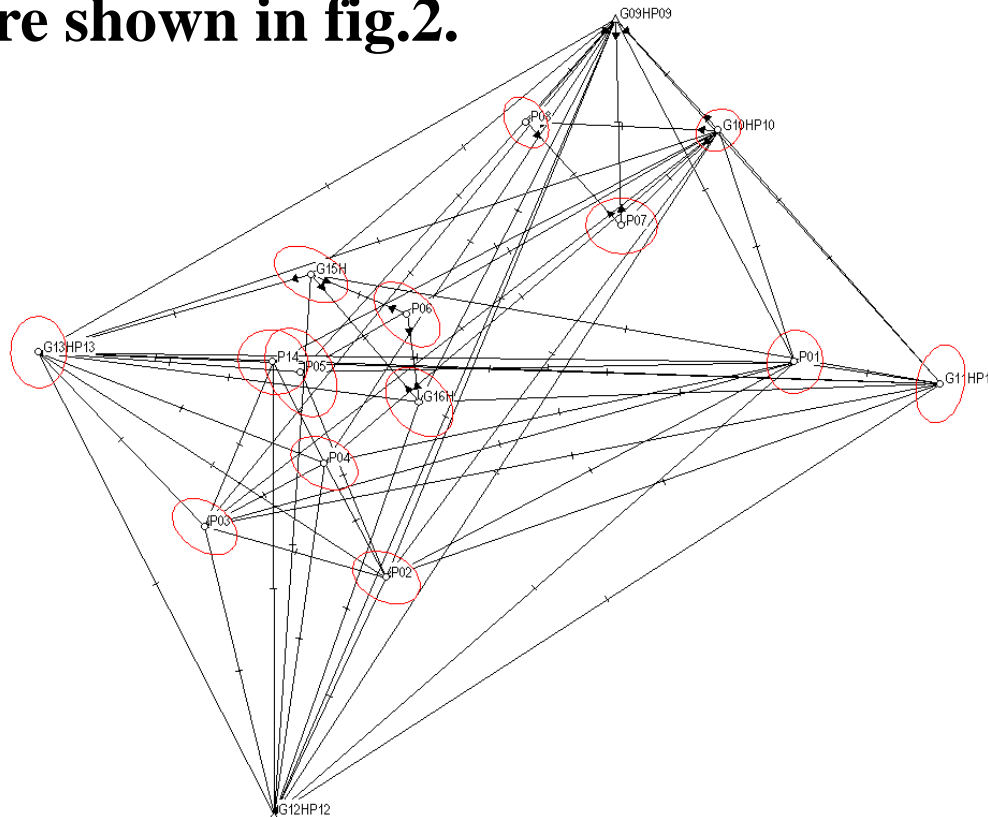
$$H_d = \sqrt{S^2 - H^2} \Rightarrow m_{H_d}^2 = \frac{4S^2 m_S^2 + 4H^2 m_H^2}{4(S^2 - H^2)}$$

According to the law of propagation of errors , while the distance is 200m and the elevation is 30m, the precision of the horizontal distance can be reached 1.6mm.

3.5 Simulation

Simulation conditions: the precision of horizontal distances is 1.6mm.

The error ellipses and the map of control network after simulation are shown in fig.2.



3.5 Simulation

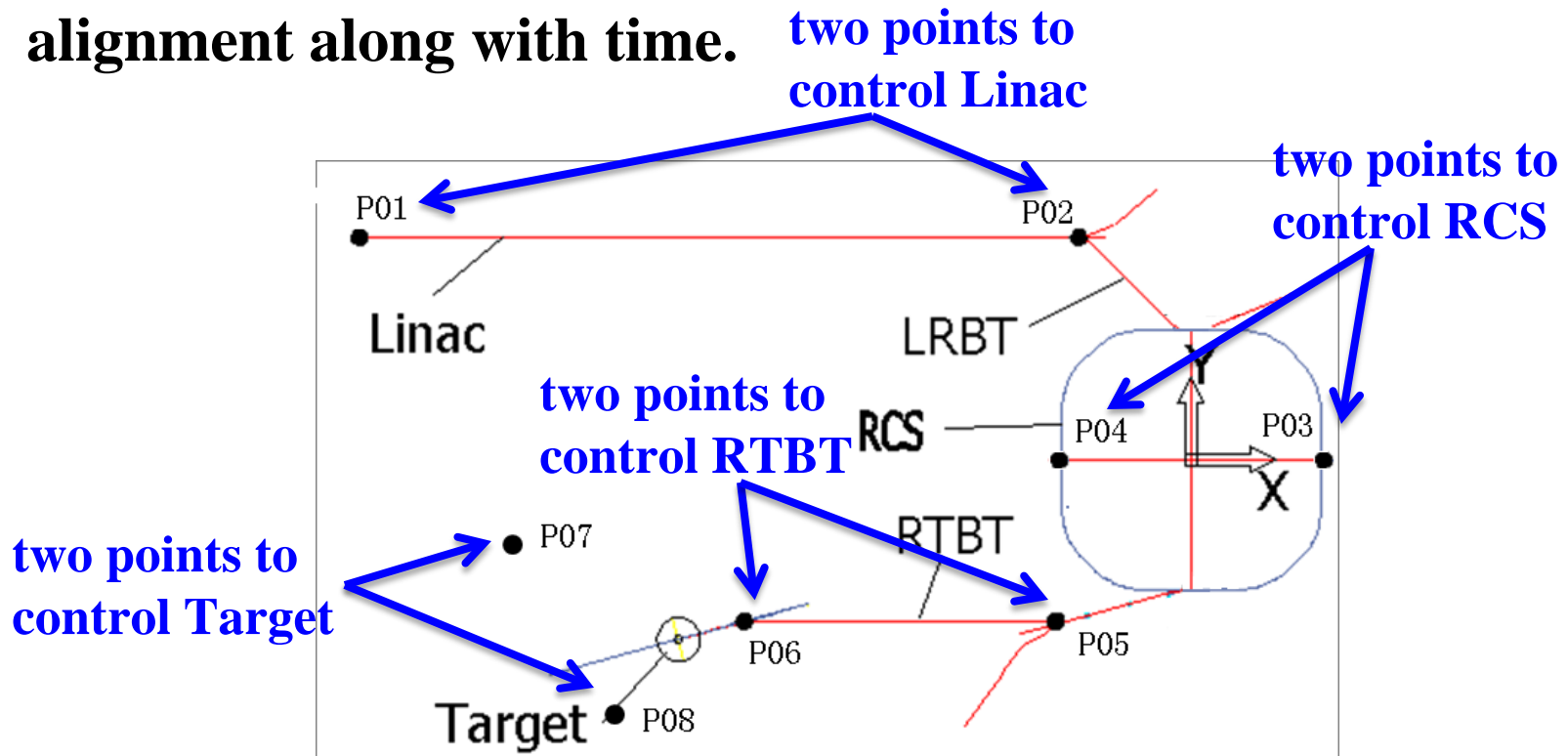
The detail results of precision estimation at most of the points are as follows:

Name	X(m)	Y(m)	MX(cm)	MY(cm)	MP(cm)
G09HP09	529949.492	391380.781	\	\	\
G12HP12	529600.901	391231.449	\	\	\
G15H	529837.475	391247.581	0.07	0.09	0.11
G16H	529781.486	391294.930	0.08	0.08	0.12
G10HP10	529900.614	391425.878	0.05	0.06	0.08
G11HP11	529789.538	391522.971	0.1	0.07	0.12
G13HP13	529803.421	391128.305	0.09	0.07	0.11
P01	529799.164	391459.243	0.08	0.07	0.11
P02	529704.696	391280.557	0.07	0.09	0.11
P03	529726.997	391201.027	0.07	0.08	0.11
P04	529754.796	391253.407	0.07	0.08	0.11
P05	529794.544	391243.097	0.11	0.09	0.14
P06	529819.921	391289.583	0.08	0.09	0.12
P07	529858.704	391383.452	0.07	0.09	0.12
P08	529903.962	391341.695	0.06	0.06	0.08
Average of Mx: 0.08		Average of My: 0.08		Average of Mp: 0.11	

4、 Design of the secondary network

4.1 Layout of the secondary network

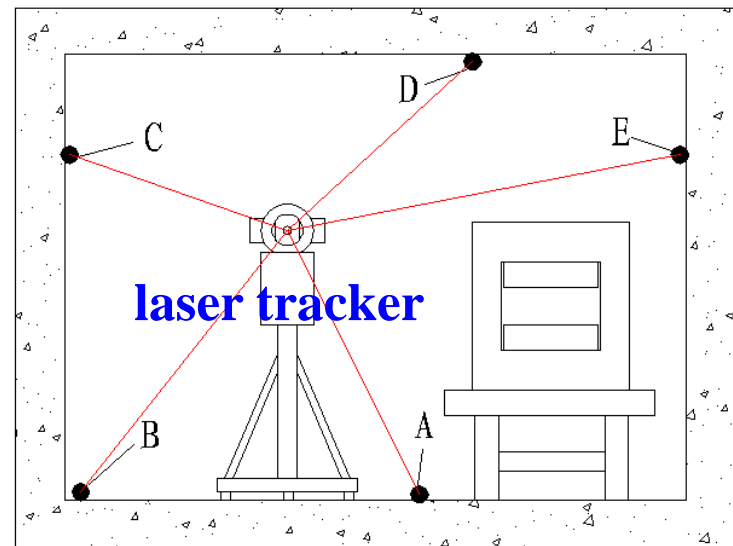
The secondary network is laid out along the accelerator tunnel. The control network is used as a reference for installing, locating and adjusting the accelerator components. It can also be used to monitor the deformation of the accelerator alignment along with time.



4.1 Layout of the secondary network

Considering the capability of laser tracker and the precision requirement of survey network, we plan to set control point sections with the interval of 6 m along the tunnel. In each section, there are five monuments, two on the floor, one on the inner wall, one on the outer wall and one on the roof.

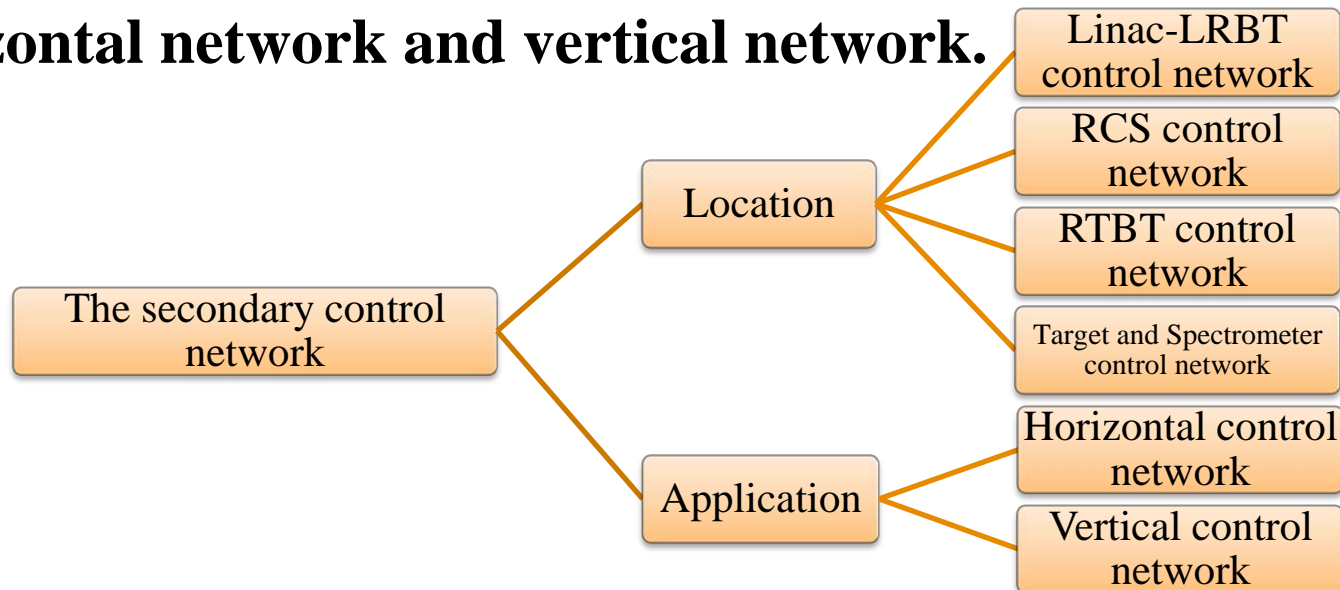
There are 36 control point sections along the Linac tunnel, 7 sections in the LRBT tunnel, 44 sections along the RCS tunnel and 26 sections in the RTBT tunnel.



4.2 Constitution of the secondary network

According to the major structure of the accelerator complex, the network can be divided into the Linac-LRBT network, the RCS network, the RTBT network, the Target and Spectrometer network.

According to the ways of measurement and the methods of data processing, secondary control network can be divided into horizontal network and vertical network.

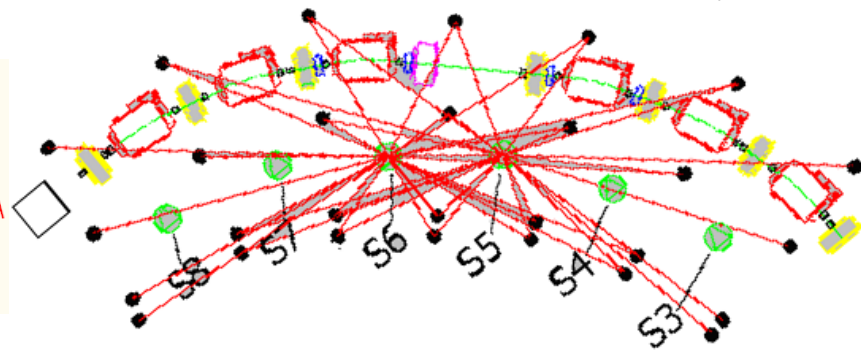
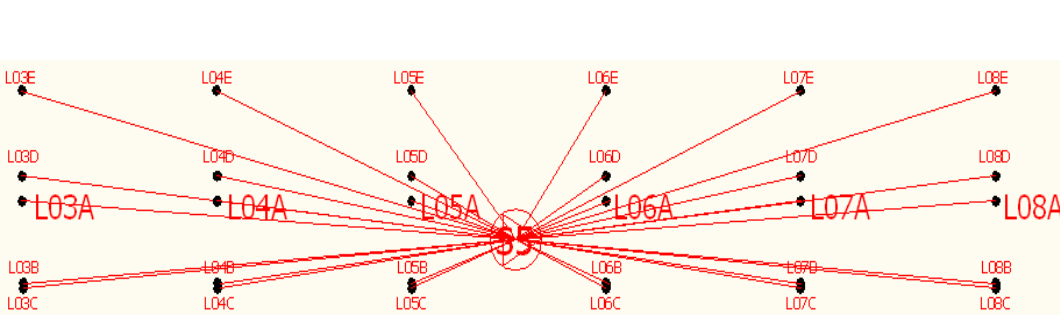


5、 Survey scheme for the tunnel control network

5.1 Survey scheme for the tunnel network

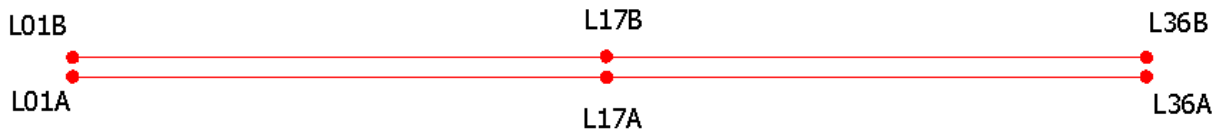
Laser tracker is used to carry out the horizontal network survey and vertical network survey together by free station method.

The survey station is set between every two neighboring sections. At each station, the laser tracker measures 3 backward sections and 3 forward sections. There are 5 control points in each section, so the laser tracker should measure 30 points at one station. The number of common control points between neighboring stations is 25. In order to obtain the horizontal coordinates and vertical coordinates, at each station we need to establish a horizontal datum for the laser tracker.

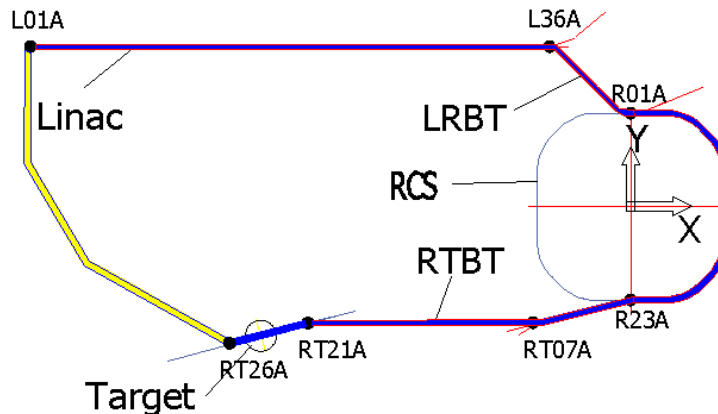


5.2 Enhanced survey for the tunnel network

□ In order to improve the precision of Linac horizontal control network, we use a total station to carry out an enhanced hexagon network survey which covers the whole Linac.



□ As the vertical network surveyed by laser tracker is not closed, the yellow leveling line is added by Leica DNA03, which can effectively decrease the accumulated errors in the tunnel vertical network survey carried out by laser tracker.



5.3 Data process of the tunnel network

□ Horizontal adjustment scheme

Take all the observations of every station as the input parameters, including distances and angles measured by laser tracker and total stations, we can get the horizontal coordinates of the tunnel horizontal network.

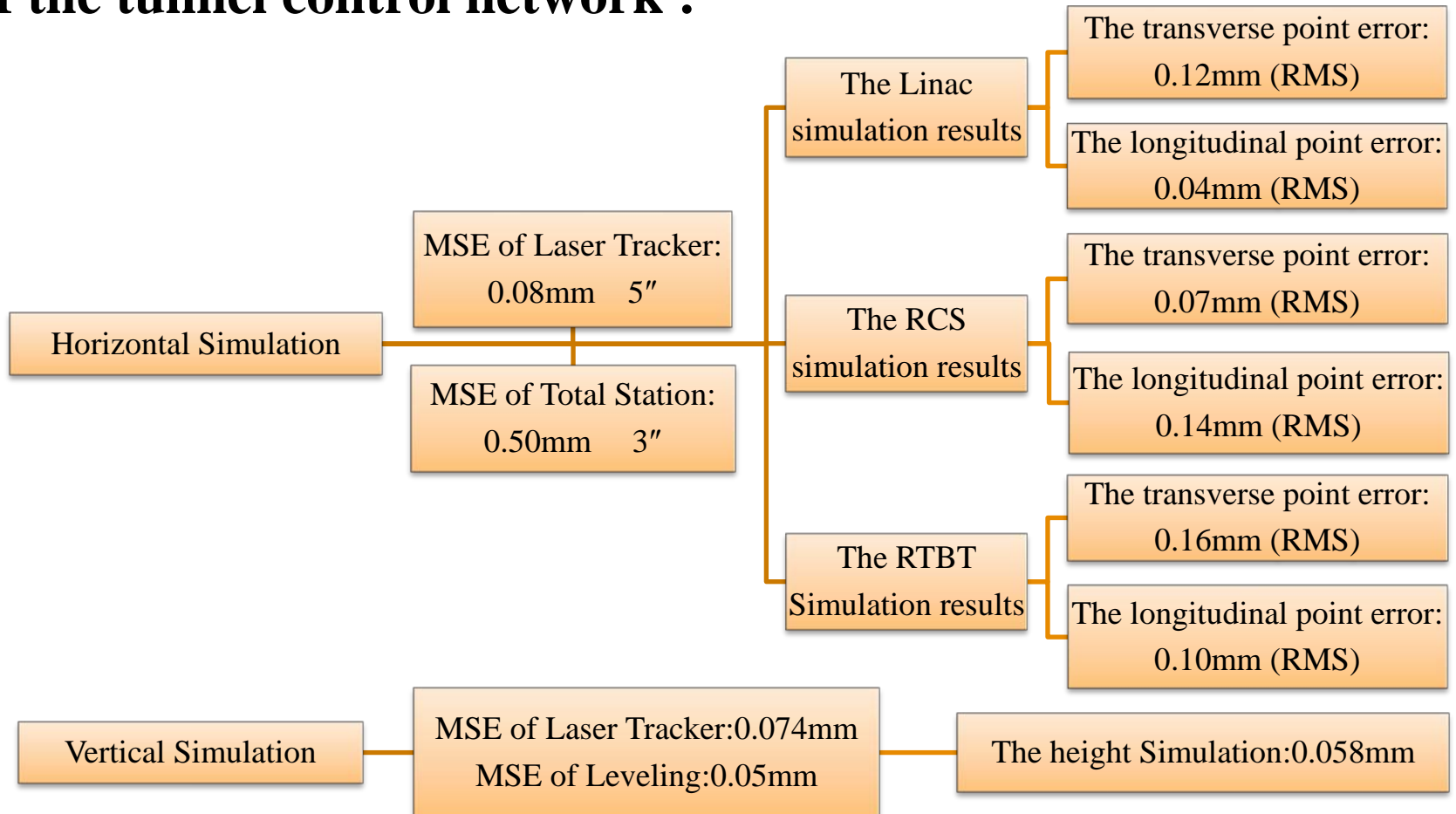
□ Vertical adjustment scheme

From the vertical coordinates measured by laser tracker and the height differences of the monuments in the yellow line we can get a group of height differences of a closed leveling.

Using these height differences to do level adjust we can get the vertical coordinates of the tunnel level network.

5.4 Simulation

The following diagram lists the simulation results of the tunnel control network :



6、 Alignment scheme for accelerator components in tunnel

6.1 Tolerance requirement of major components

The alignment tolerance requirement of the major components in CSNS:

	ΔX (mm) Transverse offset	ΔY (mm) Vertical offset	ΔZ (mm) Longitudinal offset
Components in the RCS	0.20	0.20	0.30
DTL in the Linac	0.10	0.10	0.10
Components in the Linac	0.25	0.25	0.50
Components in the RTBT	0.25	0.25	0.50

6.2 Error analysis of the final positions for some major accelerator components

The error of the final position of a component is the statistical sum of the fiducialization error, the installation error, the measurement error and the alignment network error.

In the error analysis below, the coordinates are defined as: X orientation and Z orientation are in the horizontal plane; X orientation is perpendicular to the beam, and Z orientation is as same as the moving direction of the beam; Y orientation is perpendicular to the horizontal plane.

Dipole (RCS)	Fiducialization Error (mm)	Measurement Error (mm)	Best-fit error(mm)	Installation Error (mm)	Alignment Network Error (mm)	Final Position Error (mm)
X	0.06	0.03	0.07	0.05	0.07	0.130
Y	0.06	0.03	0.07	0.05	0.058	0.124
Z	0.08	0.03	0.07	0.05	0.14	0.185

6.2 Error analysis of the final positions for some major accelerator components

Quadrupole (RCS)	Fiducialization Error (mm)	Measurement Error (mm)	Best-fit error(mm)	Installation Error (mm)	Alignment Network Error (mm)	Final Position Error (mm)
X	0.05	0.03	0.07	0.05	0.07	0.125
Y	0.05	0.03	0.07	0.05	0.058	0.119
Z	0.08	0.03	0.07	0.05	0.14	0.185

DTL (Linac)	Fiducialization Error (mm)	Measurement Error (mm)	Best-fit error(mm)	Installation Error (mm)	Alignment Network Error (mm)	Final Position Error (mm)
X	0.04	0.03	0.06	0.04	0.12	0.149
Y	0.04	0.03	0.06	0.04	0.058	0.105
Z	0.04	0.03	0.06	0.04	0.04	0.096

6.2 Error analysis of the final positions for some major accelerator components

RFQ (Linac)	Fiducialization Error (mm)	Measurement Error (mm)	Best-fit error(mm)	Installation Error (mm)	Alignment Network Error (mm)	Final Position Error (mm)
X	0.04	0.03	0.06	0.04	0.12	0.149
Y	0.04	0.03	0.06	0.04	0.058	0.105
Z	0.04	0.03	0.06	0.04	0.04	0.096

Quadrupole (RTBT)	Fiducialization Error (mm)	Measurement Error (mm)	Best-fit error(mm)	Installation Error (mm)	Alignment Network Error (mm)	Final Position Error (mm)
X	0.05	0.05	0.07	0.05	0.16	0.195
Y	0.05	0.05	0.07	0.05	0.058	0.126
Z	0.08	0.05	0.07	0.05	0.10	0.162

The end, thanks!