Measurement of the distance from nuclear reactors to detectors in Dayabay neutrino experiment

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Outline

1. Introduction of distance measurement in Dayabay neutrino experiment
2. Measurement scheme:
   - Measurement instruments
   - Layout of control points
   - GPS survey in nuclear power station area
   - Traverse survey in the tunnel
   - Trigonometric leveling
   - Leveling
3. Data processing and precision analysis:
   - GPS data processing and precision analysis
   - Total station surveying data processing and precision analysis
   - The overall precision of the distance
4. Conclusions
1. Introduction

--- Dayabay neutrino experiment

- The Daya Bay Neutrino experiment is a physical experiment, which is carrying out in GuangDong, China, is also the largest international cooperation project in basic science field at present in China.

- Dayabay neutrino experiment is a neutrino oscillation experiment by detecting neutrinos produced in nuclear reactors of dayabay nuclear station. There are 8 neutrino detectors in the tunnel.
1. Introduction

---- Dayabay neutrino experiment

neutrino detectors
1. Introduction

--- Alignment Measurement

- Distance from neutrino detectors to Daya bay reactors is essential in physics analysis in this experiment.
- Our purpose is to measure the 3D distance from 8 neutrino detectors and to 6 Daya bay reactor cores. As the picture shown, 6 Nuclear reactors are located in nuclear power station, and 8 neutrino detectors are located underground in the northwest of Dayabay nuclear power station.

Geographical location of nuclear reactors and neutrino detectors
2. Measurement scheme

---- Measurement instruments

4 kinds of instruments are investigated in this measurement:

- GPS
- total station
- level equipment
- laser tracker
2. Measurement scheme

--- layout of control points

In order to make connection of the reactor cores and detector centers, two types of control points are laid out.

– One is the new buried monuments in this measurement process, as shown in fig (a), which are mainly distributed in the tunnel region and the two entrances area of the tunnel.

– The other is the forced observation pillars already existed in nuclear power station construction, which are mainly distributed in nuclear power station region, as shown in fig (b).
The whole measurement area divides into three parts:

(1) nuclear power station region: GPS survey is carried out in this region, where direct intervisibility is severely cut off by barbed wires.

(2) in the tunnel: GPS signal can't reach this area, so we use total station and level in this area, in some part laser tracker is also used.

(3) in the tunnel entrance area: Both GPS and total station survey are carried out.
2. Measurement scheme

- GPS survey
- total station survey
- leveling
- neutrino detectors
- reactors

Fig. Sketch map of measurement scheme
2. Measurement scheme

---GPS survey experiment

- Many measuring control points are under high voltage wire. So GPS survey experiment under the high voltage wire is carried out to research the influence of high voltage wire to GPS survey.
2. Measurement scheme

--GPS survey experiment

- There are some compared baselines measured by both GPS receivers and total-stations under the high voltage wire as well as others (launch tower, near building), as table 2 shown.

- Small difference has been discovered after comparison between both method.

- The GPS survey experiment under the high voltage wire (220 KV) has shown that it could be feasible. We can ignore the influence to GPS from high voltage wire.

<table>
<thead>
<tr>
<th>the slant computed by</th>
<th>The slant computed by</th>
<th>The difference</th>
<th>The observation environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>total-station observation</td>
<td>GPS observation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>118.48645</td>
<td>118.49089</td>
<td>-0.004440</td>
<td>5-m away from 20-m-high Building, almost 15 sec</td>
</tr>
<tr>
<td>111.31130</td>
<td>111.30852</td>
<td>0.002780</td>
<td>Under the high voltage wire (220kv)</td>
</tr>
<tr>
<td>190.21070</td>
<td>190.21168</td>
<td>0.000978</td>
<td></td>
</tr>
<tr>
<td>489.40263</td>
<td>489.40396</td>
<td>0.001335</td>
<td></td>
</tr>
<tr>
<td>1126.21963</td>
<td>1126.21668</td>
<td>-0.002954</td>
<td>The longest baseline in the GPS control network</td>
</tr>
<tr>
<td>1216.59313</td>
<td>1216.58782</td>
<td>-0.005310</td>
<td></td>
</tr>
</tbody>
</table>
2. Measurement scheme

--GPS Survey outside the tunnel

- 4 GPS receivers are applied in this survey, Topcon and Sokkia.
- Every tunnel entrance and reactor core has 4 GPS control points, and other extra control points are only used to coordinate conversion.
- The 4-hour observations have been done at tunnel entrance, as well as reactor cores. Then the others is totally 4-hours.

<table>
<thead>
<tr>
<th>GPS network technology index</th>
<th>technology index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite cutoff elevation angle</td>
<td>15°</td>
</tr>
<tr>
<td>Effective satellite number in Synchronous observations</td>
<td>≥4</td>
</tr>
<tr>
<td>Numbers of observation time</td>
<td>≥2</td>
</tr>
<tr>
<td>Sampling interval</td>
<td>10”</td>
</tr>
<tr>
<td>Observation time</td>
<td>3 hours</td>
</tr>
</tbody>
</table>
We can obtain measuring point coordinates on WGS84 by GPS measurement. WGS84 is World Coordinate System, while the total station coordinate system on level surface for used in the tunnel is independent Coordinate System from WGS84.

Total station measurement is carried out on some of the control points outside the tunnel for coordinate conversion.
In the tunnel, where GPS signal can not reach, we use total station to carry out horizontal and vertical survey.

- horizontal: double traverse survey method
- vertical: trigonometric leveling method, and Leveling is also carried out in the tunnel to verify the accuracy of trigonometric leveling.
2. **Measurement scheme**

--- **Traverse survey with Total Station**

- Double traverse survey with total station is carried out in the tunnel.
- 2 Leica TDA5005 total station were used. Four survey times for each station were performed in face left and right.
- In addition, the traverse is closed in two different ways from one entrance to the other, one is through the mountain top, another is through the road outside of tunnel.

![Double traverse network](image1)

![Traverse closure of the two entrances](image2)
2. Measurement scheme

---Trigonometric leveling with Total Station---

- 2 Leica TDA5005 total station were used. Four survey times for each station were performed in face left and right.
- Reciprocal observation method is used in trigonometric leveling. When one direction observation finished, the other direction observation starts quickly. The time of reciprocal observations is short, and atmospheric environment change is insignificant, so it could offset much of the effect of earth curvature and refraction in an average of the reciprocal observations.
2. Measurement scheme

- In trigonometric leveling, Instrument height is usually measured by measuring tape, accuracy of which is better than 1 mm.
- To improve the accuracy, a standard bar is designed, of which the reading error is 0.02mm, repeatability better than 0.1mm and accuracy better than 0.3mm, as shown in fig.
2. Measurement scheme

--Leveling

- Leveling is also carried out in the tunnel to verify accuracy of trigonometric leveling. It turns out that precise trigonometric leveling survey can replace the second order leveling.
- Leica NA2 leveling was used.
3. Data processing and precision analysis  

---GPS baseline calculation

- The collected observations were processed using the software Trimble Geomatics Office.
- According to observation environment and satellite status, changing satellite altitude angles, cutting satellite tracking and selecting solution error model are carried out in Baseline Calculation.
- GPS survey base line outside the tunnel as fig shown.
3. Data processing and precision analysis

----GPS adjustment

unrestrained adjustment: decides the geometry of GPS control network

constraint adjustment: The known data should be introduced

<table>
<thead>
<tr>
<th>Unit: mm</th>
<th>B</th>
<th>L</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>The best</td>
<td>0.68</td>
<td>0.66</td>
<td>0.343</td>
</tr>
<tr>
<td>The poorest</td>
<td>2.03</td>
<td>2.3</td>
<td>18.23</td>
</tr>
<tr>
<td>average</td>
<td>0.99</td>
<td>0.99</td>
<td>6.93</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.05</td>
<td>1.06</td>
<td>7.75</td>
</tr>
</tbody>
</table>

The statistical results for adjustment in the WGS 84
3. Data processing and precision analysis

----GPS precision analysis

This figure depicts all adjustment residuals on north(X), east(Y) and height(Z). Average positional precision of GPS network is 12.6mm.
3. Data processing and precision analysis
----horizontal survey data of total station

Horizontal survey data adjustment
- detection of outliers
- adjustment
  input: horizontal angle and horizontal distance
  software: MAA
  COSA
  SURVEY

<table>
<thead>
<tr>
<th>Unit: mm</th>
<th>error</th>
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<tbody>
<tr>
<td>The best</td>
<td>1.1</td>
</tr>
<tr>
<td>The poorest</td>
<td>9.9</td>
</tr>
<tr>
<td>average</td>
<td>3.9</td>
</tr>
</tbody>
</table>

error ellipse distribution
Vertical survey data adjustment
input : altitude difference
software: ShanWei

Geometric leveling is also carried out in the tunnel, the
difference between total station
trigonometric leveling and
geometric leveling is given as shown. The difference is small.

<table>
<thead>
<tr>
<th>Unit: mm</th>
<th>error</th>
</tr>
</thead>
<tbody>
<tr>
<td>The best</td>
<td>1.56</td>
</tr>
<tr>
<td>The poorest</td>
<td>4.16</td>
</tr>
<tr>
<td>average</td>
<td>3.4</td>
</tr>
</tbody>
</table>

error in point measurement

<table>
<thead>
<tr>
<th>Unit: mm</th>
<th>difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>The best</td>
<td>0.03</td>
</tr>
<tr>
<td>The poorest</td>
<td>1.62</td>
</tr>
<tr>
<td>average</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Difference between geometric leveling and trigonometric leveling
3. Data processing and precision analysis

--- Precision analysis of Total station survey

- This Figure depicts all adjustment residuals on horizontal (X, Y) and vertical (Z) of total station network. Average positional precision of total station network is 6.5mm.
3. Data processing and precision analysis

---The overall precision of the distance

- Precision of GPS network (12.6mm) and total station network (6.5mm) in the distance measurement are introduced above. Besides, considering both the error of reactor cores to control points in nuclear power station and the measuring error of laser tracker, the overall precision of the distance is about 18 mm.
4. Conclusions

– 1. The overall precision of the distance from nuclear cores to neutrino detectors is about 18 mm in the range of 4 kilometers.

– 2. The trigonometric leveling leveling survey can replace the second order leveling.

– 3. The GPS coordinate in WGS84 could be transferred onto the Geoid trigonometric leveling.
Thank you!