RAILWAY PROJECT

Geodetic Reference System, Geodetic Control Network and Rail Construction Measurements

15.12.2017

INDEX

1 INTRODUCTION

The aim of this section is to clarify the requirements of a successful realisation of a geodetic control network and rail construction measurements. The only way to monitor the geometric construction quality is via accurate measurements. The reference system and height system has to be accurate and suitable for the needs of railway track design and construction.

The accuracy demands can be split in to two: absolute and inner accuracy. Absolute accuracy refers to the absolute position relative to the reference system. Inner accuracy can refer to the accuracy of the control network, measuring system such as a total station and a prism or the accuracy of a build railway.

Traceability is vital in engineering surveys. The chosen reference system, geodetic control network, measuring devices and surveyors all have to be traceable. This demands profound documentation and well organized surveying organization. All the surveying equipment must be calibrated in authorized metrology laboratories prior to any measurements and during the project. Field calibrations are used regularly to check the correctness of the measurements. The professional skills of the surveying personnel must be verified also.

The following recommendations and guidelines help to make sure that all the design units, contractors and authorities work in the same reference system to consolidate the planning and construction. Guidelines for specification of requirements of geodetic measurements standard SFS-EN 13231-1 Annex A must be followed carefully.

2 REFERENCE SYSTEM

2.1 Reference system

All the planning and construction will take place in a common and accurate reference system. A Common reference system is vital to avoid geodetic transformations between different reference systems as transformation produce errors in the transformed positions. Also geodetic reductions can be minimized via choosing the correct reference system. Considering the realization of reference systems in Uruguay it’s recommended to use the international reference system IGS 14.

The following items must be considered carefully when choosing the reference system for the project:

- Using a national or international reference system if possible
    - Makes it easier to handle spatial data in the future
- The quality of the realization
    - The density and quality of higher class control network (Active CORS-stations and fixed points)
    - Age of the fixed points
        - Homogenic trough out the project area

2.2 Map projection

Map projections contain always error. It’s vital to use a tangential projection so that the scale errors are minimal. For example, Gauss-Kruger projections with 1 degree bands are recommendable. The scale factor must be exactly 1.00000 at the meridian.

3 HEIGHT SYSTEM

3.1 Height system

It's recommended to use a national or an international height system. Controlling the height is very important as it's the only way to ensure the designed vertical curves and slopes are built as planned. A common height system ensures that the planned and build railway track fits together with the existing infra. If there is no suitable height system, it must be established and adjusted as much as possible to the existing height datum.

A suitable height system is an orthometric height system which has coverage over the project area. Things to consider:

- Density of the control network (fixed points)
- The age of the realization

3.2 Geoid Model

Orthometric heights are based on physical measurements referenced to the MSL (geoid) whereas GPS measurements are truly 3D and give ellipsoidal heights. In order to transform GPS measurements to orthometric heights a geoid model is needed.

4 MEASURING TECHNIQUES

Measuring techniques to be used in establishing the geodetic control network and construction measurements are described below:

Satellite Measurements
Relative Static Positioning

- Establishing horizontal/(vertical) control to control network
- High accuracy vectors between at least two receivers
- Accuracy: sub centimetre, even millimetre level accuracy
- Session times vary from 0,5 hour to multiple hours depending on vector length

Real Time Kinematic Positioning

- Mapping positions in real time
- Machine Control
- Accuracy: horizontal 1 cm and above, height 2 cm and above
- Suitable for substructure measurements

Total Station Measurements
Traversing

- EDM Distance measurements and angular measurements
- Establishing horizontal/vertical control to control network using control points measured with relative static positioning producing lower class control points for construction measurements

Construction measurements

- EDM Distance measurements and angular measurements
- Millimetre level accuracy
- Suitable for superstructure measurements (especially determining rail geometry)

Levelling
Line levelling

- Vertical control for control network
- Recommended to use precise levelling instruments (sub millimetre accuracy)

Construction measurements

- Laser levelling

5 GEODETIC CONTROL NETWORK ACCURACY AND RELIABILITY REQUIREMENTS

5.1 Geodetic control network

To ensure the accuracy and the reliability the following standards and guidelines should be taken to account.

Network Structure

The network is built of higher class control points which are built in pairs. The pairs should be approximately 1.5 – 2.0 km away from each other along the track line. The pair points should be from 350 to 500 meters away from each other. Visibility between the pair points must be ensured. The higher class control points are measured with relative static measurements. The lower class points are build 150 – 200 meters away from each other along the track line. The lower class points are measured with traversing. For all the points the heights are determined by levelling.

Construction of Fixed Points (Control Points)

In order to have a quality geodetic control network the fixed points must be static. If the points move the points can be considered destroyed and they are no use in controlling the position of the track. Therefore, the following regulations must be followed carefully.

Building platform:
- Bedrock, concrete structure, large land stones
- If not possible, the points must be pile-driven to the bedrock

Structure of points:
- Metallic tubes, bars or bolts (drilled in bedrock) with unambiguous centre cross
- To minimize the chance of vandalism, all points must be build hidden or so that vandalism is hard execute
- Easy to spot colourful plastic tubes attached to the fixed points (1 m long) makes it easier to find the fixed points (only in areas where vandalism is not a risk)

Monumentation:
- Point Cards of each point
    - Point number
    - Coordinates (Hz + V)
    - Height
    - Structure

Accuracy Tolerance

The accuracy tolerances are expressed as relative *ppm accuracy between neighbouring points.

Point Class	Horizontal accuracy (*ppm)	Vertical accuracy (*ppm)
Higher (Pair points)	10	10
Lower	20	10

***parts per million*

Observations where distance is lower than 200 meters the maximum standard deviation is 4 mm.

Reliability Requirements

The reliability of the geodetic control network is heavily dependent upon network structure, redundancy and following strictly the given guidelines.

Network Structure

- Static network structure
  - Vectors in a loop 3 – 5
  - All new higher class control points must have at least two vectors which are measured straight to the national control points
  - The control network points should be build and measured with relative static positioning according to International Geodetic Guidelines

- Traverse
  - All points that are visible within 400 meters from observation station should be observed to achieve a network like structure in order to locate possible blunders
  - To achieve quality measurements bad weather conditions such as heat haze, heavy rain or fog, should be avoided when observations are made

- Levelling line
  - A simple line where fore and back sights must not differ more than 20 meters in length.
  - The maximum length of a sight must be 100 meters.
  - It's recommended to use at least two national control points along the railway track that are located at each end of the levelling line. This way the closure is complete and the levelling process is efficient.
  - To achieve quality measurements bad weather conditions such as heat haze, heavy rain or fog, should be avoided when observations are made

Redundancy

- Static network
  - 15 % of all the vectors should be measured twice to increase the reliability of the network and to find blunders

- Traverse
  - 4 series of observations at each station
    - If the series closure is higher than the given tolerance accuracy tolerances, repeat the 4 series
- Levelling line
  - Levelling line doesn't have redundant measurements, yet the high accuracy of the levelling device should expose any possible blunders
    - In case of high closure error, the measurements must be repeated
      - If error is still the same size, the error is located in the used national control points, remove the points which contain error
    - If no national control points exist near the project area (10 km) the vertical control points can be measured with relative static positioning, if an accurate geoid model is available and the Infrastructure Manager approves this method

5.2 Control Network Adjustment Calculus

Adjustment calculus consists of least squares error equation adjustment

Static control network
- Free network adjustment
  - Inner accuracy and reliability
- Constrained network adjustment
  - Attaching fixed points to the network to ensure network quality and to give the final coordinates to the new fixed points

Traverse
- Blunder detection by keeping pair points free and constrained in turns
- Constrained network adjustment
    - Attaching fixed points to the network to ensure network quality and to give the final coordinates to the new fixed points

Line levelling
- Only constrained network adjustment where both line heads are constrained

The design and adjustment of the control network must be left for the professionals. Documentation of the adjustment and analysis is a vital part of quality control.

6 REQUIREMENTS FOR SURVEYING DEVICES AND GEAR

Calibration
- All used surveying devices must be calibrated in national metrology laboratories prior to use
- Field Calibration is a vital part of quality control

Satellite Receivers and Antennas
- Static Accuracy Hz 3 mm + 0,1 ppm / V 4 mm + 0,5 ppm
- RTK Accuracy Hz 10 mm + 1 ppm, V 20 mm + 1 ppm
- Ability to receive GPS L1, L2 and Glonass L1, L2 signals

Total Station
- Geodetic control network
    - Inner accuracy 1 mm point accuracy (horizontal + vertical) (Inner accuracy: between the total station and prism; Distance and angle measurements + Automatic Target Recognition to a prism)
- Construction measurements
    - Inner accuracy 1 - 3 mm point accuracy (horizontal + vertical) (Inner accuracy: between the total station and prism; Distance and angle measurements + Automatic Target Recognition to a prism)
    - Rail survey adapter 1 – 2 mm inner accuracy (for example a Rail Measurement Trolley)

Levelling instruments
- Precise levelling instrument accuracy 0.7 mm/km

7 SURVEY PLANNING

Prior to any surveys (control network surveys or construction surveys) a survey plan is made and handed to the Infrastructure Manager who inspects it in collaboration with an External Auditor.

The surveying plan consists of:
- List of national control points and analysis of their suitability for the survey
- Measuring technique and equipment
- Observation planning
- Geodetic and adjustment calculation methods and programs used
- Surveying personnel
- Design maps
    - The project area
    - National control points locations (horizontal and vertical)
    - Higher point class designed position (pair points) – network drawing
    - Lower point class designed position – network drawing

8 DOCUMENTATION

The documentation consists of the following:

Reference system and height system
- Realisation
- Parameters
- Map projection
- Datum
- Sources (Official documentation of the used reference system)

Control point network
- Monumentation
- List of national control points used as starting points for the horizontal and vertical control
- Technique used for the surveying and equipment
- Adjustment calculus reports, analysis and point precision (relative accuracy between points)
- Control network drawing (static survey, traverse, levelling line)
- List of the new points, coordinates, heights

Calibration of surveying equipment
- Official documents of calibration certificates

9 QUALITY CONTROL

To ensure the quality of the used reference system, height system and control network, an External Auditor must inspect the chosen reference system, height system and the control network. This author will accept or reject plans, surveys and documentary in collaboration with the Infrastructure Manager.