Rail Baltica
Coordinated by RB Rail

TECHNICAL SPECIFICATION

# GEODETIC NETWORK ESTABLISHMENT FOR DESIGN STAGE OF RAIL BALTICA HIGH SPEED RAILWAY

RBDG-MAN-038-0100

Revision: 1.0

Author: Geogios Papastamos

Date: 28.11.2022

# Document Development and Approval:

| Ownership | |
|---|---|
| Document Owner | Virtual Design and Construction Department |

| Approved by | Decision No. | Date |
|---|---|---|
| CTO | - | 06.06.2022 |
| RB Rail MB | | 28.11.2022 |

# Document History

This document has been issued and amended as follows:

| Revision | Issue Date | Author | Issue purpose | Description of changes |
|---|---|---|---|---|
| 1.0 | 20.05.2022 | Georgios Papastamos | First issue | Technical specification for implementation of Geodetic Network during design stage |
| 2.0 | | | | |

# Contents

# ACRONYMS AND ABBREVIATIONS

The following acronyms and abbreviations are used throughout this document:

| Abbreviation | Definition |
|---|---|
| BIM | Building Information Management. Set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space. Including PIM (project information model) and AIM (asset information model). |
| BoQ | Bill of Quantities. An itemised list of classified materials, parts, and labour together with their unit cost and description what is basis for cost calculation, required to construct, install, maintain, and/or repair the infrastructure, specifically extracted from Rail Baltica BIM models. |
| CDE | Common Data Environment – RB Rail AS/Client is the owner of this platform. It is a central repository where construction project information is housed. |
| CP | Control Point – geodetic marks/benchmarks to be built in order to create new geodetic network for implementation of High-Speed Railway. |
| DG | Design Guideline. Set of predefined and standardized technically and economically justified engineering and design solutions for Rail Baltica infrastructure to be applied at design, construction and operation phases of Rail Baltica Railway, which forms an integral part of this Technical Specification. The Design guidelines may be changed by the Client, therefore, the Agreement always refers to the most current version of the Design guidelines. |
| DRCHS | Digital Information Requirements for Construction and Handover Stages. |
| DTD | Detailed Technical Design of Rail Baltica project. |
| EIR | Employer's Information Requirements. BIM Requirements which define the information that will be required from the Consultant for the development of the project and for the operation of the completed built asset. |
| GIS | Geographic Information System. |
| INS | Inertia navigation system. |
| PUO | Public Utility Organisations/Owners. |
| RB ELL22 | The Unified Project dedicated coordinate system along the whole Rail Baltica Project Corridor. |
| RBDatum | The Geodetic Reference System dedicated to the Rail Baltica Project. |
| RBR | RB Rail AS. |
| SSP | Supervision Service Provider – service provider awarded with an Agreement to conduct supervision services for construction or railway and geodesy network construction specified in this document. |
| TBM | Tunnel Boring Machine. |
| TGMT | A Railway track geometry measuring trolley system. |

# DEFINITIONS

The following terms are used throughout this document:

| Term | Definition |
|---|---|
| BIM Model | 3D models containing information (PIM & AIM). |
| Consultant | Service provider awarded with an Agreement to design Rail Baltica high speed railway with geodetic survey delivery. |
| Client | RB Rail AS. |
| Country | Republic of Estonia/Republic of Latvia/Republic of Lithuania. |
| Programme | Representation (including graphical) of the time schedule, tasks and milestones agreed between the Consultant and Client at the initial stage of the Agreement's implementation and forming a part of legal obligations of the Consultant. |
| Rail Baltica highspeed railway | a new 249 km/h conventional double track electrified European standard gauge (1435 mm) railway line on the route from Tallinn through Pärnu - Riga -Panevėžys - Kaunas to Lithuanian - Polish border, with the connection of Kaunas - Vilnius. |
| ORDER 0-3 Network | The hierarchy of the Project's Geodetic Network. (0 is the highest order) consisting of control points (CP). |
| Primary Geodetic Network | This network is indicated by two levels: Order 0 (CP0) and Order 1 (CP1). |
| Secondary Geodetic Network | This network is indicated by two levels:  Order 2 (CP2) and Order 3 (CP3). |
| Service | Supervising Authority. Case by case it can be RB Rail, and/or Implementing Parties, and/or Resident Engineer. |
| Digital Format | For drawings, 2D or 3D, is a vector format (.dwg, .dgn, .dxf, .ifc and etc). For Tables or lists in xls, or ASCII format. Documents in word, or ascii format. |

# 1 Introduction

1. The following technical specifications are made to make sure that Rail Baltica highspeed railway construction accuracy is in accordance with all applicable legislation and standards in all Baltic states and to ensure that all parties (e.g. designer, contractor, authorities, supervision etc.) are working in the same reference system to consolidate the planning, designing and to coordinate construction and maintenance.

2. It is mandatory that geodetic network for Rail Baltica project must be optimal in respect of geometry, accuracy and reliability. For this purpose, a dedicated to the Project geodetic network will be implemented, which will be connected to the local States Coordinate Systems to assure high accuracy during construction works, supervision and maintenance.

## 1.1 Geodetic Network

3. The Consultant shall follow EU directives, all Country's construction and other national legislation, EU standards, Country-specific legislation/standards/rules and other legal acts applicable for the provision of construction of geodetic network and construction supervision services.

# 2 Reference system

4. It is within the intention of RBR to establish a unified Reference System, along the whole corridor alignment. This Reference system (RBDatum) will be based on the Global Reference System WGS84. Due to the Rail Baltica project alignment length, it is important to define a coordinate projection system with the following characteristics:

    (a) Low distortion of engineering grids

    (b) Continuous, without different projection parameters zones, able to extend for kilometres

    (c) Unique scale factor along the alignment at ground level

5. When it is completed, it will be the RB ELL22 unified Project dedicated Coordinate System, applicable along the whole alignment of Rail Baltica Project.

6. A high accuracy levelling traverse will run along the whole alignment to secure internal geometry and will also be a part of the RB ELL22 system.

7. RBDatum will be directly connected to each country local coordinate system (presented in Table 1) and will have dedicated Coordinate System RB ELL22 when it is established.

Table 1. Countries' Coordinate and Altimetry systems

| Country | Horizontal | Vertical |
|---|---|---|
| Estonia | L-EST 97 | EH2000 |
| Latvia | LKS-92 | LAS-2000,5 |
| Lithuania | LKS94 | LAS07 |

8. In each country, all designing, and construction shall be carried out according to local coordinate system RBDatum. At cross-border section in addition to local coordinate system, WGS84 shall be used for seamless connection of neighbouring sections.

9. For acquisition of WGS 84 system, cross calculation parameters can be used, either country wide parameters or locally applied parameters. Precision calculation parameters shall be assessed with Static positioning. Cross calculation parameters shall be coordinated and approved with SSP.

# 2.1 Detailed Technical Design and existing geodetic network

10. To create the RBDatum unified geodetic network Order 0, along Rail Baltica railway line, concrete monuments shall be constructed approximately every 5Km along the alignment, at accessible locations, not more than 2Km far from the designed railway alignment, that will be connected to the national geodetic grid.

11. Those Geodetic benchmarks shall be built by DTD Designer according to the specifications of this document. Due to that, existing national network shall be investigated to provide highest accuracy necessary for implementing high speed railway (Figure 1).

12. At Cross-Border section Consultant is obligated to build 5 geodetic benchmarks in distance of 2,0 km extending both sides of neighbouring countries.

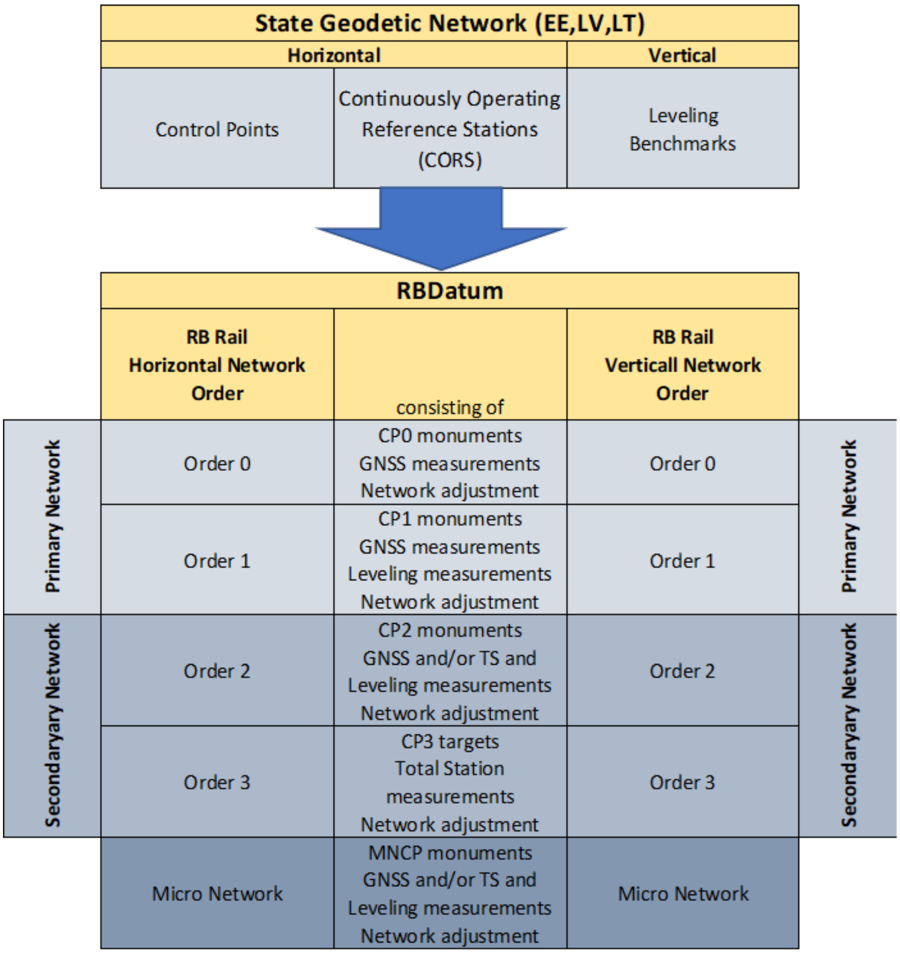


Figure 1. Geodetic Networks Classification

### 2.1.1 Estonian national geodetic network

13. Estonian national geodetic network system consists of three different classes of geodetic reference points:

    (a) I class – 13 points (12 ground points and 1 GNSS). Distance between points 70-110 km with square error +/- 1 cm accuracy.

    (b) II class – 199 points. Average distance between points is 15 km with square error +/- 1 cm accuracy.

    (c) Densification Network – 3922 points. Average distance between points is 5 km with square error +/- 1...3 cm.

14. In Estonia, the heights of the EVRS system are denoted by the abbreviation EH2000. The calculation of EH2000 heights was based on the EVFR2007 solution (Solution 201703 / NKG2005LU). Heights' accuracy is estimated at +/- 1,7mm. The Reference Ellipsoids and Datums, as well as the Map Projections that are mainly used in each country and for Rail Baltica Design Studies stage are summarized in the following tables of paragraphs 2.2.

### 2.1.2 Latvian national geodetic network

15. Geodetic reference system of Latvia is formed by geodetic coordinate system of Latvia (hereinafter LKS-92) and normal heights system of Latvia (hereinafter LAS-2000.5). Implementation of the model of the geodetic reference system in an area shall be ensured by the national geodetic network.

16. LKS-92 shall be realized by Class 0, Class 1 and Class 2 markers of the global positioning network and system of permanent global positioning base stations "Latvian Positioning System" (hereinafter - LatPos):

    (a) Class 0 of the global positioning network (G0) with an accepted standard deviation 0 mm (4 points);

    (b) Class 1 of the global positioning network (G1) with the standard deviation 20 mm versus a network of Class G0 (41 point);

    (c) Class 2 of the global positioning network (G2) with the standard deviation 25 mm versus a network of Class G1 (752 points);

    (d) LatPos base stations with the standard deviation of co-ordinates 20 mm versus a network of Class G0 (48 pcs).

17. LAS-2000,5 shall be realized by Class 1 and Class 2 markers of the levelling network:

    (a) Class 1 of the levelling network (N1) with the standard deviation 1.0 mm/km (1911 point);

    (b) Class 2 of the levelling network (N2) with the standard deviation 2.0 mm/km (606 points).

18. The Reference Ellipsoids and Datums, as well as the Map Projections that are mainly used in each country and for Rail Baltica Design Studies stage are summarized in the following tables of paragraphs 2.2.

### 2.1.3 Lithuanian national geodetic network

19. Lithuanian national GNSS network consists of four different class of geodetic points:

(a) 0 class – 4 points: Akmeniškiai (point code number – 34S-0311), Dainavėlė (point code number – 52S-0409), Meškonys (point code number – 73S-0312), Šašeliai (point code number – 55S-0408). Error of these points with respect to the initial geodetic points of the European geodetic networks shall not exceed 9 mm;

(b) I class – 48 points. Distance between points 40 km, error of these points with respect to the initial geodetic points of 0 class geodetic networks are less than 6 mm;

(c) II class – 1026 points. Distance between points 7-10 km, error of these points with respect to the initial geodetic points of 1 class geodetic networks are less than 5 mm;

(d) III class - density of geodetic points of the network – 1 point / 5 km2. The position error of the geodetic points of the third class GPNS network with respect to the initial geodetic points of the first and second class GPNS networks shall not exceed 5 cm.

20. The Reference Ellipsoids and Datums, as well as the Map Projections that are mainly used in each country and for Rail Baltica Design Studies stage are summarized in the following tables of paragraphs 2.2.

## 2.2 Baltic Reference data

This paragraph identifies all data related to existing situation of Refence systems in 3 Baltic states. Table 2 and 3 is summarized information for The Consultant to use this data during Geodetic Network implementation process.

**Table 2.** Local Reference Ellipsoids/Datums data

| Country | Estonia | Latvia | Lithuania |
|---|---|---|---|
| Country identifier | EE | LV | LT |
| CRS identifier | EE_L-EST97 / EST_LAMB | LV_LKS-92 / LV_TM | LT_LKS94 / LT_TM |
| CRS valid area | Estonia | Latvia | Lithuania |
| CRS scope | Coordinates of Points of the National Geodetic Network of Estonia | | |
| CRS remarks | | The LKS-92 coordinates are determined from the final solution of the EUREF BAL92 GPS-campaign | The LKS94 coordinates are determined from the final solution of the EUREF BAL92 GPS-campaign |

| Country | Estonia | Latvia | Lithuania |
|---|---|---|---|
| Datum identifier | L-EST97 | LKS-92 | LKS94 |
| Datum alias | | Latvijas geodeziska koordinatu sistema 1992 (Latvian Geodetic Coordinate System 1992) | Lietuvos koordinačių sistema 1994 (Lithuanian Coordinate System 1994) |
| Datum type | geodetic | geodetic | geodetic |
| Datum anchor point | | 4 points of the EUREF BAL92 GPS-campaign | 4 points of the EUREF BAL92 GPS-campaign |
| Datum realization epoch | 1997 | 1992 | 1994 |
| Datum valid area | Estonia | Latvia | Lithuania |
| Datum remarks | The ETRS89 coordinates are derived from the final solution of EUREF-ESTONIA97 in ITRF96, Epoch 1997.56 by transformation Estonia. In Gubler, E., Torres, J.A., Hornik, H. (eds): Report on the Symposium of the IAG European Reference Frame (EUREF) held in Prague, 2-5 June | LKS-92 is consistent with ETRS89; LKS-92 is based on Resolution Number 213 of the Government of Latvia of June 4, 1992 | LKS94 is consistent with ETRS89 see Resolution Number 936 of the Government of Lithuania of September 30th, 1994 |
| Prime meridian identifier | Greenwich | Greenwich | Greenwich |
| Prime meridian Greenwich longitude | 0° | 0° | 0° |
| Prime meridian remarks | | | |
| Ellipsoid identifier | GRS 80 | GRS 80 | GRS 80 |
| Ellipsoid alias | New International | New International | New International |
| Ellipsoid semi major axis | 6 378 137 m | 6 378 137 m | 6 378 137 m |
| Ellipsoid shape | TRUE | TRUE | TRUE |
| Ellipsoid inverse flattening | 298.2572221 | 298.2572221 | 298.2572221 |
| Ellipsoid remarks | see Moritz, H. (1988): Geodetic Reference System 1980. Bulletin Geodesique, The Geodesists Handbook, | see Moritz, H. (1988): Geodetic Reference System 1980. Bulletin Geodesique, The Geodesists Handbook, | see Moritz, H. (1988): Geodetic Reference System 1980. Bulletin Geodesique, The Geodesists Handbook, |

| Country | Estonia | Latvia | Lithuania |
|---|---|---|---|
| | 1988, Internat. Union of Geodesy and Geophysics | 1988, Internat. Union of Geodesy and Geophysics | 1988, Internat. Union of Geodesy and Geophysics |

**Table 3.** Local Map Projections

| Country | Estonia | Latvia | Lithuania |
|---|---|---|---|
| Coordinate system identifier | EST_LAMB | LV_TM | LT_TM |
| Coordinate system type | projected | projected | projected |
| Coordinate system dimension | 2 | 2 | 2 |
| Coordinate system axis name | northing | X / northing | X / northing |
| Coordinate system axis direction | North | North | North |
| Coordinate system axis unit identifier | metre | metre | metre |
| Coordinate system axis name | easting | Y / easting | Y / easting |
| Coordinate system axis direction | East | East | East |
| Coordinate system axis unit identifier | metre | metre | metre |
| Operation identifier | EST_LAMB | LV_TM | LT_TM |
| Operation valid area | Estonia | Latvia | Lithuania |
| Operation method name | Lambert Conformal Conic Projection with 2 standard parallels | Transverse Mercator Projection | Transverse Mercator Projection |
| Operation method name alias | | Gauß Krüger Projection | Gauß Krüger Projection |
| Operation method formula | Lambert Conformal Conic Projections, in Snyder, J.P., Map Projections – A Working Manual, Washington 1987, pages 107-109 | Transverse Mercator Mapping Equations, in Hooijberg, Practical Geodesy, 1997, pages 81-84 | Transverse Mercator Mapping Equations, in Hooijberg, Practical Geodesy, 1997, pages 81-84 |

| Country | Estonia | Latvia | Lithuania |
|---|---|---|---|
| Operation method parameters number | 6 | 6 | 6 |
| Operation parameter name | lower parallel | latitude of origin | latitude of origin |
| Operation parameter value | 58°00’ N | 0° | 0° |
| Operation parameter remarks | | 0°, the Equator | 0°, the Equator |
| Operation parameter name | upper parallel | longitude of origin | longitude of origin |
| Operation parameter value | 59°20’ N | 24° E | 24° E |
| Operation parameter name | latitude grid origin / zero parallel | false northing | false northing |
| Operation parameter value | 57°31’03.19415” N | -6 000 000 m | 0 m |
| Operation parameter name | longitude grid origin | false easting | false easting |
| Operation parameter value | 24°00’ E | 500 000 m | 500 000 m |
| Operation parameter remarks | | only one zone | only one zone |
| Operation parameter name | false northing | scale factor at central meridian | scale factor at central meridian |
| Operation parameter value | 6 375 000 m | 0.9996 | 0.9998 |
| Operation parameter name | false easting | width of zone | width of zone |
| Operation parameter value | 500 000 m | 6° | 6° |
| Operation parameter remarks | | only one zone of 6° width with central meridian 24° E for LV in use | only one zone of 6° width with central meridian 24° E for LT in use |

# 2.3 Geodetic control network accuracy and reliability requirements

## 2.3.1 Network structure – Control Points Classification

21. RBDatum Geodetic control network is classified in four different types of Control Points with different density level. (Figure ):

    (a) CP0 – ORDER 0 Network control points every 5Km- highest precision primary level of network;

    (b) CP1 – ORDER 1 Network control points every 1.0Km-1.5Km- primary level of network;

    (c) CP2 – ORDER 2 network control points every 400m- secondary level of network;

    (d) CP3 – ORDER 3 network control points on Catenary posts- secondary level of network;

    (e) MNCP – Micro-Networks- directly connected to ORDER 0-3 levels and used for bridges, tunnels, and other structures.

22. All prepared data shall be integrated into RBR GIS platform and updated according to provided data. Prepared material shall be useable and linked with DTD designed BIM models. ORDER Network is described in this document chapter 3.2.

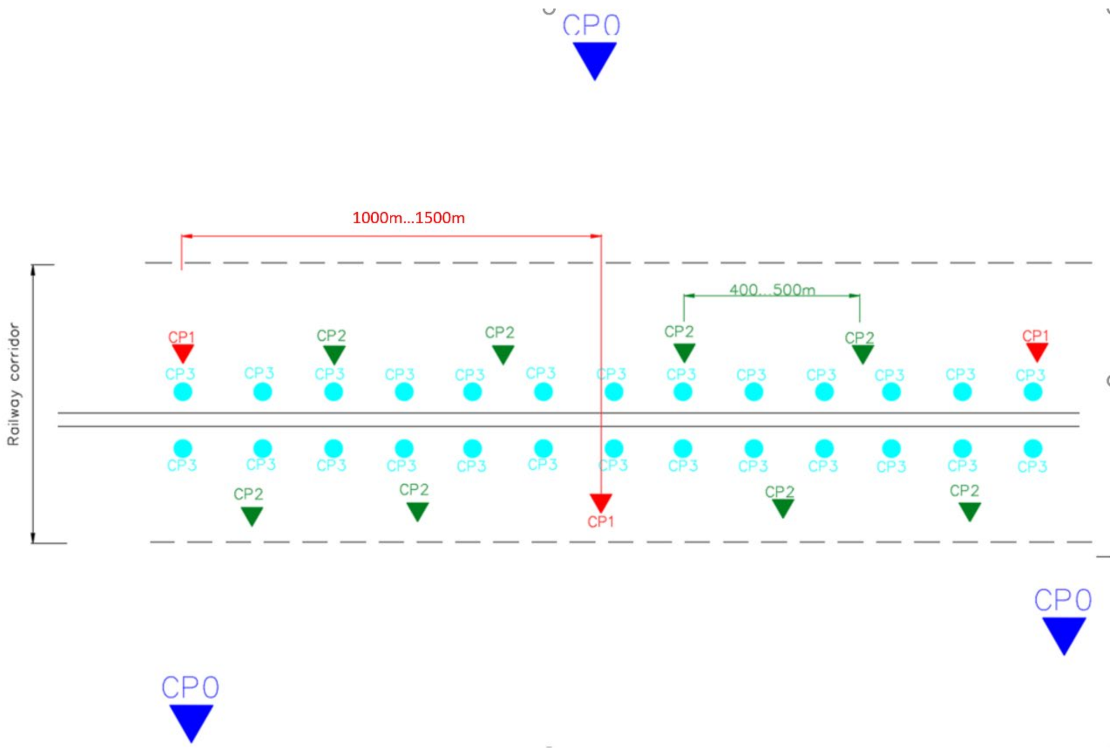


Figure 2 Scheme of CP for Rail Baltica project

# 3 Geodetic Network workflow

## 3.1 General instructions to the Consultant

23. The survey works needs to be carried out by Consultant during the DTD stage of the Rail Baltica Project and this task shall include the following:

    (a) Establishment throughout the entire alignment length, of a unified basic horizontal network and a unified levelling control network within RB Rail Reference System (RBDatum) and connection with the already existing one (Figure 3).

    (b) Establishment of ORDER 0 horizontal and levelling control networks connected with the basic networks.

| | RBDatum | | | |
|---|---|---|---|---|
| obligation of | RB Rail Horizontal Network Order | consisting of | RB Rail Verticall Network Order | obligation of |
| Designer Consultant | Order 0 | CP0 monuments<br>GNSS measurements<br>Network adjustment | Order 0 | Designer Consultant |
| Contractor | Order 1 | CP1 monuments<br>GNSS measurements<br>Leveling measurements<br>Network adjustment | Order 1 | Contractor |
| | Order 2 | CP2 monuments<br>GNSS and/or TS and<br>Leveling measurements<br>Network adjustment | Order 2 | |
| | Order 3 | CP3 targets<br>Total Station measurements<br>Network adjustment | Order 3 | |
| | Micro Network | MNCP monuments<br>GNSS and/or TS and<br>Leveling measurements<br>Network adjustment | Micro Network | |

Figure 3 Geodetic Network Obligation Status

24. All topographic measurements shall be accompanied by the required corrections due to pressure, temperature, and refraction.

25. For all survey works, the Consultant obliged to update the Client.

26. All topographical data (raw data, coordinates files, drawings) shall be stored in digital form and shall be transmitted to the Client CDE immediately submitted respectively and/or through e-

mail provided it is requested by the Client and at a frequency that would have been mutually determined.

27. For all survey works required for the DTD of the Project, RBDatum shall be used.

28. All survey measurements, as well as the calculations, the results, and the drawings for all the survey works herein shall be submitted for approval to the Client in digital form too and shall be signed by the Consultant Survey Department.

29. The Service shall supply the Contractor with all required topographical information upon which the existing design of the Project has been based.

### 3.1.1 Method Statement

30. For all the above and before the commencement of the Project's design works, the Consultant is obliged to submit to RB for approval the Methodology for the execution of all Survey Works. Method Statement shall include but not limited to the following references. Content of information to be included in the document is presented in Table 4.

**Table 4.** Method of survey works content for Consultant

| No. | Content topics |
|---|---|
| 1. | General part -Introduction |
| 1.1 | Summary description of the project |
| 1.2 | Contractual obligations |
| 1.3 | Staffing of the survey department |
| 1.4 | general description of the methodology |
| 2. | Reference Network |
| 2.1 | Establishment & increase of networks |
| 2.2 | Existing conditions |
| 2.3 | New network requirements |
| 2.4 | Preliminary activities |
| 2.5 | Contents of the submittals |
| 2.6 | Equipment |
| 2.7 | Solution methods, accuracy |
| 2.8 | Software |
| 2.9 | Maintenance |
| 3. | Theoretical data |

| No. | Content topics |
|---|---|
| 3.1 | General description |
| 3.2 | Requirements |
| 3.3 | Software |
| 3.4 | Submittals |
| 3.5 | Forms |
| 3.6 | Approvals |
| 3.7 | Files |
| 4. | Surveys works |
| 4.1 | General description |
| 4.2 | Requirements |
| 4.3 | Methods |
| 4.4 | Equipment |
| 4.5 | Software |
| 4.6 | Forms |
| 4.7 | Approvals |
| 4.8 | Submittals |
| 5. | Health & safety |
| 5.1 | General description |
| 5.2 | Equipment |
| 5.3 | Conditions |
| 5.4 | Transportation |
| 6. | Exchange of data with the Client/Service |
| 6.1 | General description |
| 6.2 | Templates of electronic files |
| 6.3 | Forms |
| 6.4 | Frequency |

| No. | Content topics |
|---|---|
| 6.5 | Storing |
| 6.7 | Filling |

31. All the above shall be approved and inspected by the Client/Service within regular time periods to be agreed upon, based on the progress of the construction works.

32. The completeness of the survey works methodology is an essential factor, to timely resolve any possible deficiencies and problems that may affect the operation of the monitoring system of the DTD survey works. Therefore, the submitted methodology must be approved by the Client/Service and any eventual comments must be considered by the Consultant. The recording of the results and the filing is performed based on the project's segmentation into Sections, as specified in advance. Data shall be provided according to RB Rail Design Guideline requirements. It is evident that the structure of the documents' filing system must be accompanied by the appropriate digital data format for the purpose of the correct and immediate data exchange with the Client.

## 3.2 Basic Surface Network (CP0) - ORDER 0

### 3.2.1 Horizontal network (CP0) – ORDER 0

33. Control Point 0 (CP0). The CP0 Horizontal Network is the highest precision primary level network which is basic and most important Geodetic Network of the Project, for the following reasons:

    (a) It is the connection between the RBDatum Geodetic Network and each country's State Geodetic Network. (Horizontal and Vertical);

    (b) all activities including densification of networks are referred to this network (CP0);

    (c) it is the most accurate of all networks related to the project (ORDER 1-3, MNCP);

    (d) it will be the asset that will remain for all stages of the project (construction & operation).

34. CP0 horizontal network should be delivered by the Consultant. All the raw data of the measurements should be delivered to the Client for Postprocessing and Adjustments' control.

35. Control points (CP0) points will be constructed along the railway corridor at intervals of approximately 5Km, not more than 2Km away from the alignment, at easily accessible locations and outside the influence zone of the Project or related roads (Figure 4).

36. The locations for CP0 construction should be at solid ground, with 10° from horizon clear sky view (no trees, structures, or other obstacles), not close to electric power lines. The positioning of these points shall be defined in cooperation with the Service.

37. Construction specifications for CP0 type of Benchmarks (monuments) are presented in Annex 1 of this document.

38. Measurements of this network shall be based on the GPS system, while the coordinates shall be given based on RBDatum reference system and the WGS84 reference system. The above

network shall be linked with at least three points of the State reference network, for a length of 50Km of alignment.

39. The network shall be connected to at least three (3) points of the closest Continuously Operating Reference Stations (CORS) (EstPos, LatPos, LitPos), or Similar Private compatible included to the State Geodetic Points Database.

40. CP0 points shall be measured using Static Positioning method to get sub centimetre horizontal accuracy (Semi major error ellipsis axis ≤10 mm).

41. Real Time Kinematic Positioning is forbidden.

42. CP0 Network measurements shall be carried out according to these instructions (Figure 4):

    (a) Per receiver setup at least 9 independent baselines should be measured simultaneously (3 to CORS, 2 to State Benchmarks, at least 4 to neighbouring CP0 control points)

    (b) GDOP should be less than 7 and number of satellites more than 10.

    (c) Acceptable occupation times for Static at 95% confident level and Double Frequency Receivers: 20 min + 2min per km (the longest baseline of a setup should be considered for this calculation).

    (d) Recommended epoch rate: Static -15s.

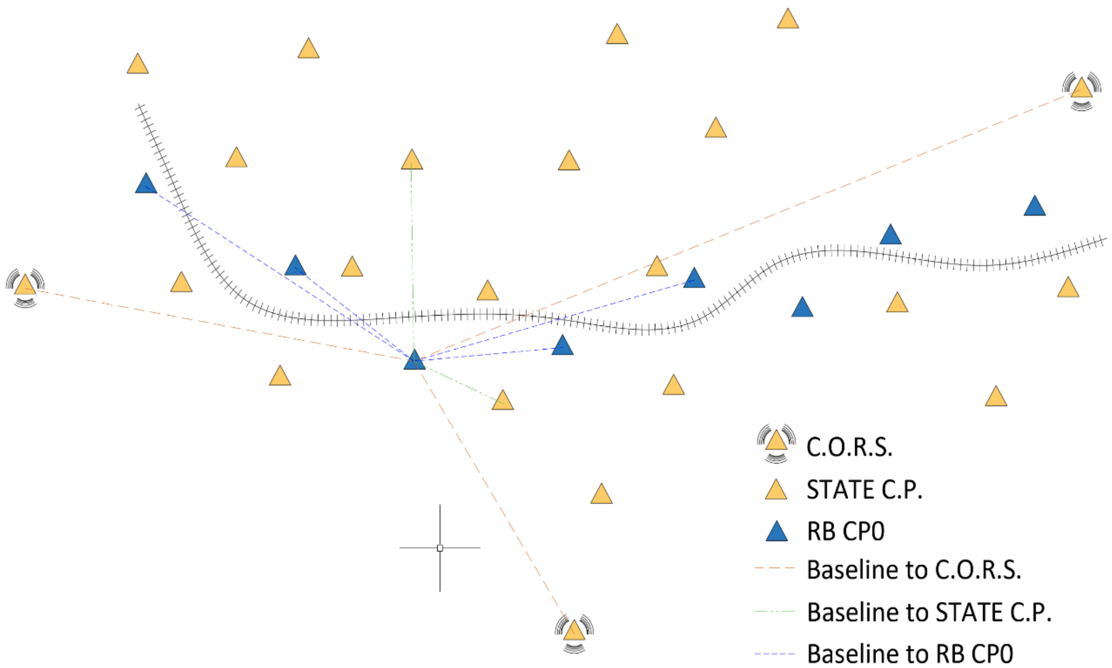


Figure 4. Scheme of GNSS baselines for each CP0 of Rail Baltica project

43. The solution and the adjustment of the network shall be carried out with the use of the appropriate software (using the method of the least squares), at a three-sigma confidence level. The coordinates shall be given based on the RBDatum reference system and on the WGS84 reference system, with the respective accuracy and standard deviations.

### 3.2.2 GNSS receivers minimum required specifications

44. To achieve correct accuracies, it is needed to follow these steps:

(a) dual-frequency with at least 9 channels;

(b) accuracy in static tracing shall be Hz ±(3 mm + 0,1 ppm) / V ±(4 mm + 0,5 ppm);

(c) ability to receive at least GPS L1, L2 and Galileo E1, E5a, E5b signals.

### 3.2.3 The software for the processing of the GPS

45. The software processing GPS measurements shall be capable to:

(a) be used in Windows environment and to trace the location using all tracing techniques - import / export Rinex files, as well as to produce reports for each executed work;

(b) transfer data, process data bases, automatically selecting the bases for solution and controls;

(c) control the closing of triangles / polygons;

(d) to resolve networks, change the reference systems (datum) and programming of measurements;

(e) select a local reference system that has been entered by a user;

(f) automatic conversion of coordinates to any reference system;

(g) select the geoid model;

(h) output results in various formats such as .dxf, ascii and other, to be compatible with all CAD and GIS systems;

(i) to perform automatic hierarchy of unified solution of data concerning the static and kinematic tracing (post processing kinematic & RTK) and conventional ground level observations;

(j) to perform automatic conversion of kinematic measurements after the solution of statistics using Least Squares Methodology;

(k) final coordinates values must be given showing to 3rd decimal.

46. The GPS system and the software to be used shall be submitted to the Client/Service for approval.

### 3.2.4 General rules

47. The identification of the points of the basic horizontal network shall be permanent and, in a way, ensuring its preservation during the construction of the Rail Baltica project, as well as for their future use.

48. The methodology for the above works shall be submitted to the Client/Service for approval, prior to the commencement of works.

49. The primary measurements, the calculations, the results, their accuracy, the description, the securing of the points and the network diagrams shall be submitted each time to the the Client/Service in a digital form as well.

50. To achieve quality measurements bad weather conditions such as heat haze, heavy rain or fog, should be avoided when observations are made.

51. In case of high closure error, measurements shall be repeated.

### 3.2.5 CP0 Levelling Network

52. CP0 Levelling Network should be delivered by the Consultant.

53. All the raw data of the measurements should be delivered to The Client for postprocessing and adjustments' control.

54. The CP0 elevation control network will be established at the CP0 monuments, with elevation benchmarks as described at the monument's construction specifications.

55. This network will be measured by means of geometrical levelling traverses allet-retour and will be related with each State elevation network. Moreover, it shall consist of an adequate number of loops, to ensure the maximum possible accuracy at its adjustment phase. The geometric levelling traverses shall be open, fully constrained on both ends to the levelling benchmarks of the existing State elevation network or neighbouring DTD, RBR benchmarks.

56. The levelling traverse shall pass over all ORDER 0 benchmarks and monuments, heading from the beginning to the end of the DTD project, and connecting each benchmark/monument with its previous and next. The connection to the State levelling network shall be done with additional allet-retour traverse lines, at least at the two edges of the project. It is recommended that additional intermediate connections of the main levelling line with State Benchmarks to be made (e.g. every 5-7Km), for control purposes.

57. The elevation points shall be calculated using the least squares adjustment method. The accuracy of measurements of the network shall be in the order of ±1mm/Km.

58. The instruments to be used shall be high precision digital levels, with a minimum accuracy of ±0.7mm/Km, along with their corresponding invar rods to achieve the accuracy required and shall be submitted to the Client/Service for approval. Hardware adjustment for environmental conditions shall be applied to the digital levels at least once per day, according to the temperature variations during the day.

59. The identification of the points of the levelling network shall be permanent and, in a way, ensuring their preservation during the construction of the Project, as well as for their future use.

60. The measurements, the calculations, the results, the description, the securing of the points and the network diagrams shall be submitted to the Service in a digital form as well.

61. The maximum length of a sight must be 30 meters, and the back sight/fore sight lengths from the same level station should be approximately equal.

62. To achieve quality measurements bad weather conditions such as heat haze, heavy rain or fog, should be avoided when observations are made.

63. In case of high closure error(s), measurements shall be repeated.

64. Requirements for the equipment and methodologies are described in Annex 1 Table 7 .

## 3.3 Construction of control points.

65. The construction of a geodetic mark and the materials used depends on the type of geodetic network and the characteristics of the soil at the location of the geodetic mark, which is determined in the design of the geodetic work and survey planning. Geodetic marks shall be secured in ground with concrete foundations with anchor placed below the freezing point of the ground. Each constructed point shall meet required accuracy tolerance between neighbouring points (Table 5).

Table 5. The accuracy tolerances are expressed as relative *ppm accuracy between neighbouring points

| Point class | Horizontal accuracy (*ppm) | Vertical accuracy (*ppm) |
|---|---|---|
| CP1 | 2 | 1 |
| CP2 | 4 | 1 |

66. Observations where distance is lower than 200 meters the maximum Hz standard deviation is 2mm.

67. CP spatial data shall be part of Rail Baltica project as BIM models, for this reason all plans and documentations shall be prepared according to DG BIM EIR general requirements. Every control point shall be identified by unique code according to DG BIM EIR requirements. Spatial data should be linked or integrated directly into the modelling structure and the data model of the BIM.

68. New control points shall be built and marked according to Rail Baltica specifications or each Baltic country local legislation:

   (a) Estonia – „Geodeetiliste tööde tegemise ja geodeetilise märgi tähistamise kord, geodeetilise märgi kaitsevööndi ulatus ning kaitsevööndis tegutsemiseks loa taotlemise kord" – 06.07.2013.

   (b) Latvia – Cabinet of Ministers Regulations No.497 "Regulations for local geodetic network".

   (c) Lithuania –"Dėl techninių reikalavimų reglamento GKTR 2.12.01:2001 patvirtinimo", Dėl Valstybinės geodezijos ir kartografijos tarnybos direktoriaus 2000 04 12 įsakymo NR. 28 „Dėl techninių reikalavimų reglamento GKTR 2.08.01:2000 patvirtinimo" and „Lietuvos Respublikos geodezijos ir kartografijos įstatymas".

69. Every Point Card shall have information required by local legislation and WGS84 coordinates. At cross-border sections (10km) every control point control card shall also include neighbouring country information as required by neighbouring country legislation.

70. Design life for all CPs shall be at least 30 years.

## 3.4 Cross-border section

71. Cross-border section is 10km long section that extends 5,0 km to both neighbouring countries. At Cross-border section each Control Point shall have RBDatum coordinate sets and WGS84 (Table 6).

Table 6. Cross border sections data

| Estonia – Latvia border section | Latvia – Lithuania border section |
|---|---|
| WGS84 and | WGS84 and |
| RB ELL22 and/or | RB ELL22 and/or |
| L-EST97 | LKS-92 |
| LKS-92 | LKS-94 |

72. Due to different height systems used in all Baltic States a common height system based on Amsterdam 0 shall be established in Cross border sections by the Consultant and adjusted according to required accuracy to existing height datums used in Baltic States, unless RB ELL22 is already established and delivered.

## 3.5 Documentation

73. Construction of new geodetic grid shall be documented according to applicable law in specific country where works has been done. In addition to requirements stated in legislation following reports shall be provided. At cross-border section control point documentation shall be done according to both neighbouring country legislation

74. In the course of the surveying works a report of measurement work shall be created which must consist of:

    (a) List of measuring instruments (type, numbers and specification),

    (b) Description of the measurement scheme

    (c) Results of the inspection and calibration of the measurement instruments and the measurement data

    (d) In the course of calculation works a report shall be created which must consist:

    (e) Description of the calculation's methodology.

    (f) Used software.

    (g) The measurement scheme and calculation result together with the accuracy estimates.

    (h) Documentation of constructed control points shall consist of following:

    (i) Reference system and height system

(j) realisation;

(k) parameters;

(l) map projection;

(m) datum;

(n) sources (Official documentation of the used reference system);

(o) Control point network

(p) monumentation information including picture of control point and construction drawings;

(q) maintenance specification;

(r) list of national control points used as starting points for the horizontal and vertical control;

(s) technique used for the surveying and equipment;

(t) adjustment calculus reports, analysis and point precision (relative accuracy between points);

(u) control network drawing (static survey, traverse, levelling line);

(v) list of the new points, coordinates, heights.

# 3.6 Geodetic grid construction supervision

75. To ensure the quality of construction geodetic reference system, height system and control network an RBR shall inspect the chosen reference system, height system and the control network.

76. In accordance to high speed railway construction accuracy requirements and scope of work defined in respective local law, RBR shall perform all necessary tasks to ensure that the quality of constructed geodetic network is in accordance to all applicable laws and standards for constructing highspeed railway.

77. The main tasks (not limited to) before construction works RBR is obligate to:

(a) to get obtained with defined requirements of design solutions for establishing of geodesy grid;

(b) to develop quality control system of geodetic works in accordance with the specifics and scope of the geodetic works to be performed;

(c) to get acquainted with Designer/Consultant developed work execution plan and quality assurance plan for geodetic works, in case of any discrepancies with respective national requirements and design solutions, object such Designer/Consultant 's proposals and give notification to the Client;

(d) review, approve and provide opinion for Designer/Consultant Survey Plan before beginning of works;

(e) verify imposed standards and regulations;

(f) check and coordinate the compliance of the Designer/Consultant 's subcontractors with the terms of the Contract;

(g) check and verify calibration certificates of instruments used for survey works, inform the Client about the use of non-compliant equipment;

(h) to review and approve Designer/Consultant method of statement.

# 4 References

Design Guideline documents.

# 5 Annexes

## Annex1. Detailed Technical requirements

Table 7. Equipment and Methodologies per activity

| | TOTAL STATION | | | Level | | | Rod | | GNSS | | | | | Laser Scanning | TGMT | Aerial Mapping | Photogrammetry | GPR Locator |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| activity | Low 5" | Mid 2" | High 1" | Optical | Optical w micrometer | Digital | Telescopic | Invar | Static | Fast Static | RTK | PPK | GIS | | | | | |
| **Geodetic Network Establishment** | | | | | | | | | | | | | | | | | | |
| ***0-Connection with State*** | | | | | | | | | | | | | | n/a | n/a | n/a | n/a | n/a |
| ***1-Close to Project*** | | | | | | | | | | | | | | n/a | n/a | n/a | n/a | n/a |
| ***2-ROW*** | | | | | | | | | | | | | | n/a | n/a | n/a | n/a | n/a |
| ***3-Maintenance*** | | | | | | | | | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| **Cadastral/Expropriation surveys** | | | | n/a | n/a | n/a | n/a | n/a | n/a | n/a | | | | | n/a | | n/a | n/a |
| **Preliminary Surveys** | | | | | | | | | | | | | | | | | | |
| ***Aerial Mapping*** | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | | n/a | | | n/a |
| ***Conventional*** | | | | | | | | | n/a | n/a | | | | | n/a | n/a | | n/a |
| ***ROW*** | | | | | | | | | n/a | n/a | | | | | n/a | | | n/a |
| ***Underground facilities*** | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | |
| **Construction Surveys** | | | | | | | | | | | | | | | | | | |
| ***Geodetic Networks*** | | | | | | | | | | | | | | | | | | |
| Geodetic Network Control | | | | | | | | | | | | | | n/a | n/a | n/a | n/a | n/a |
| Geodetic Network Densification | | | | | | | | | | | | | | n/a | n/a | n/a | n/a | n/a |
| Geodetic Micro Network Establishment | | | | | | | | | | | | | | n/a | n/a | n/a | n/a | n/a |
| **Expropriation Stakeout** | | | | n/a | n/a | n/a | n/a | n/a | n/a | n/a | | n/a | | n/a | n/a | n/a | n/a | n/a |
| **Data extraction** | office | | | | | | | | | | | | | | | | | |
| **Staking Out** | | | | | | | | | | | | | | | | | | |
| Earthworks | | | | | | | | | n/a | n/a | | n/a | | n/a | n/a | n/a | n/a | n/a |
| Mid accuracy structures' staking | | | | | | | | | n/a | n/a | | n/a | | n/a | n/a | n/a | n/a | n/a |
| High accuracy structures' staking | | | | | | | | | n/a | n/a | | n/a | | n/a | n/a | n/a | n/a | n/a |
| Rails initial installation staking | | | | | | | | | n/a | n/a | | n/a | | n/a | | n/a | n/a | n/a |
| Tamping Loops surveying | | | | | | | | | | | | n/a | | n/a | | n/a | n/a | n/a |
| **Field Changes** | as Stakeout | | | | | | | | | | | | | | | | | |
| **Request for Inspection** | as Stakeout | | | | | | | | | | | | | | | | | |
| **Intermediate Quantity Surveys for IPCs** | | | | | | | | | | | | | | | | | | |
| Earthworks | | | | | | | | | n/a | n/a | | n/a | | | n/a | | | |
| Mid accuracy structures | | | | | | | | | n/a | n/a | | n/a | | | n/a | n/a | | |
| High accuracy structures | | | | | | | | | n/a | n/a | | n/a | | | n/a | n/a | | |

| activity | TOTAL STATION | | | Level | | | Rod | | GNSS | | | | | Laser Scanning | TGMT | Aerial Mapping | Photogrammetry | GPR Locator |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low 5" | Mid 2" | High 1" | Optical | Optical w micrometer | Digital | Telescopic | Invar | Static | Fast Static | RTK | PPK | GIS | | | | | |
| **Final Quantity Surveys** | as Intermediate Quantity Surveys | | | | | | | | | | | | | | | | | |
| **As built surveys / QA/QC** | as Intermediate Quantity Surveys | | | | | | | | | | | | | | | | | |
| **Maintenance** | | | | | | | | | | | | | | | | | | |
| **Geodetic Network Control** | | | | | | | | | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| **Rail Geometry** | | | | | | | | | n/a | n/a | | | | n/a | | n/a | n/a | n/a |
| **Rail Clearance** | | | | | | | | | n/a | n/a | | | | | | n/a | n/a | n/a |
| **Geotechnical & Structural Monitoring** | | | | | | | | | | | | | | | | | | |
| **Preconstruction surveys, for Monitoring** | | | | | | | | | n/a | n/a | | | | | n/a | | | n/a |
| **Deformation Monitoring surveys** | | | | | | | | | | | | | | | | | | n/a |
| **Post construction surveys, for Monitoring** | | | | | | | | | n/a | n/a | | | | | n/a | | | n/a |

NOT ALLOWED
ACCEPTABLE
RECOMMENDED
MANDATORY

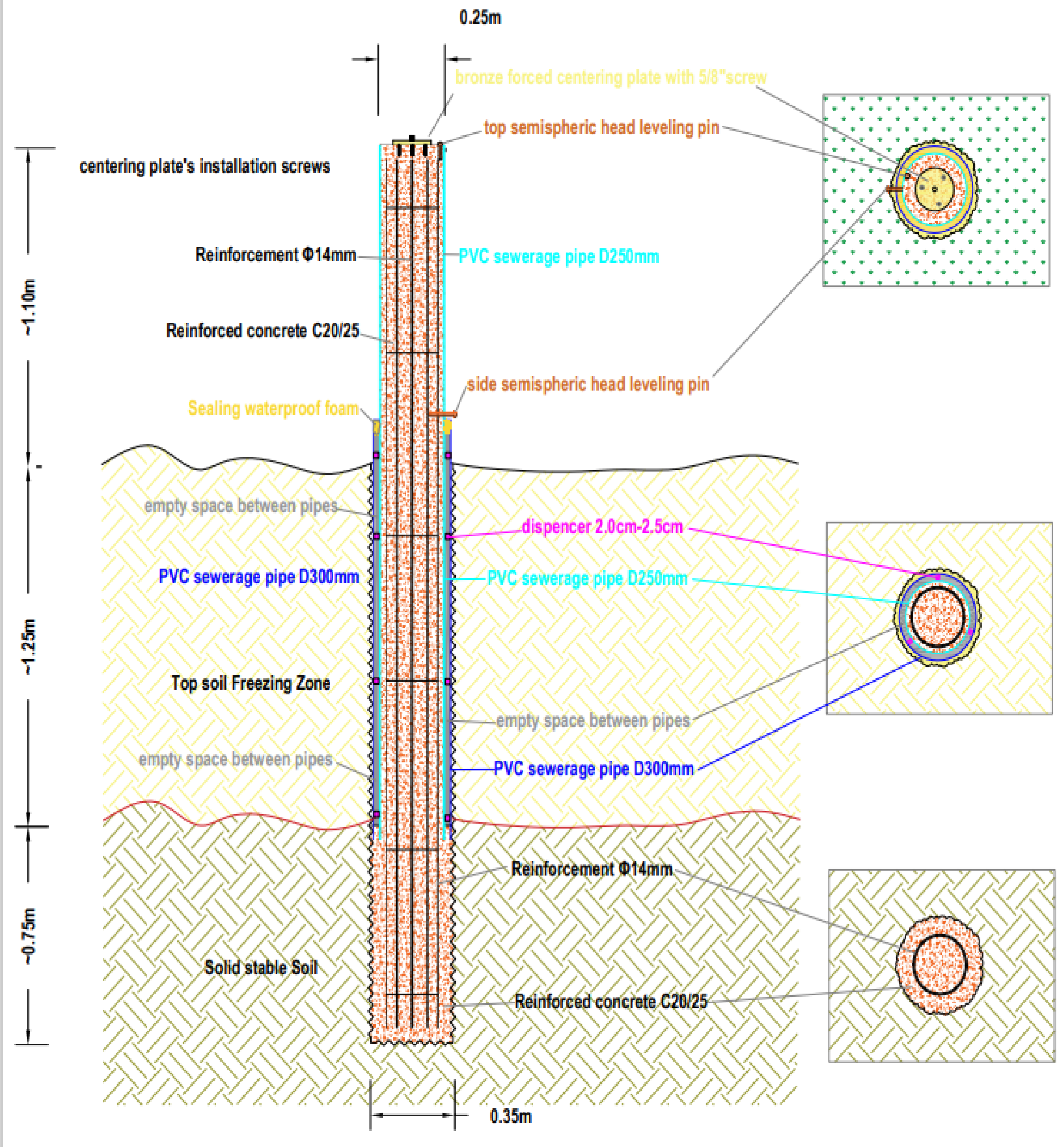


Figure 6. Monument for CP0, CP1, CP2, MNCP at non-urban areas, and if possible, at urban areas.

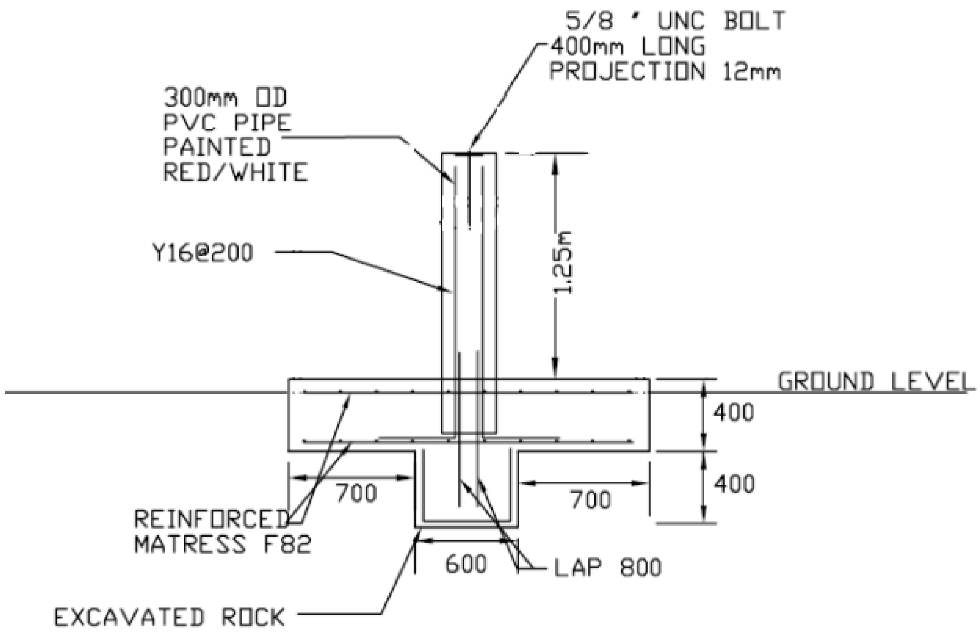


Figure 7. Monument for CP0, CP1, CP2, MNCP at urban areas. (a)

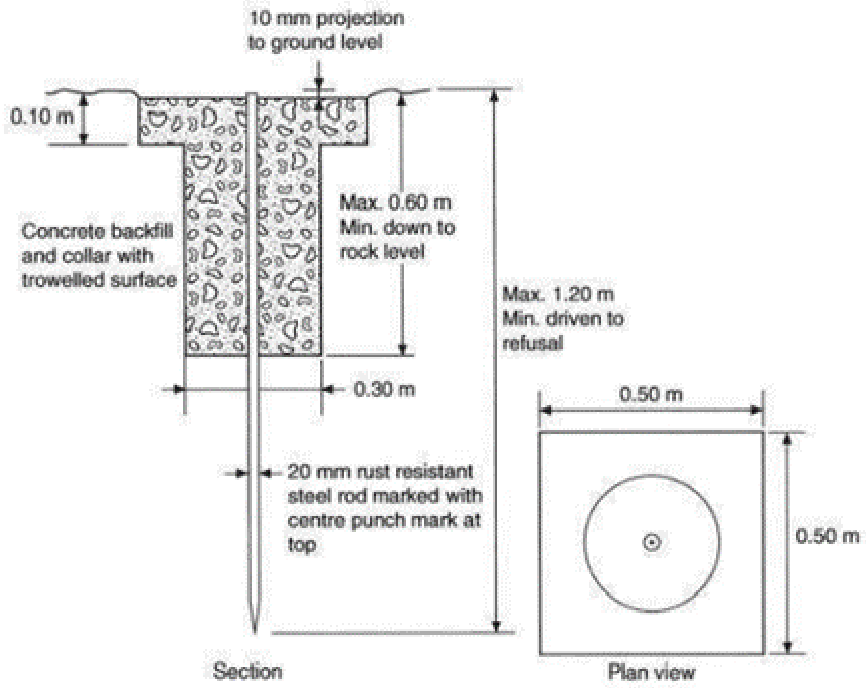


Figure 7.
Monument for CP0, CP1, CP2, MNCP at urban areas (a)

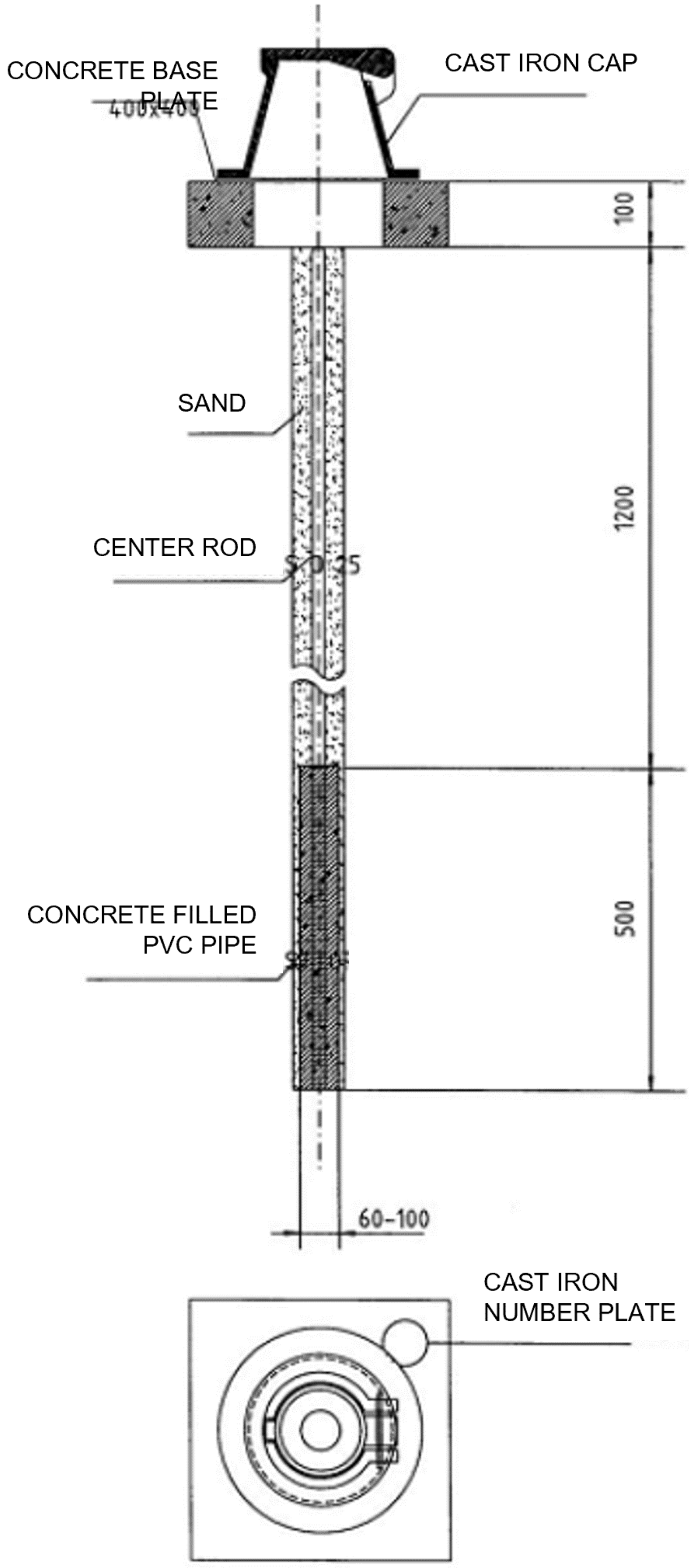


Figure 7. Monument for CP0, CP1, CP2, MNCP at urban areas (b)

Table 7. GNSS Method vs Order level

| **ORDER** | **0** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|---|
| **Technique** | | | | | |
| Classic Static | ✓ | ✓ | ✓ | ✓ | ✓ |
| Fast Static / Rapid Static | | | ✓ | ✓ | ✓ |
| Guide to minimum station spacing km [1] | 10 | 5 | 0.5 | N/A | N/A |
| Typical station spacing in km [2] | 10-100 | 5-15 | 0.5-5 | >0.05 | N/A |
| Independent occupations per station [3]<br>at least 3 times (% of total stations)[4]<br>at least 2 times (% of total stations)[4] | 40%<br>100% | 20%<br>100% | 10%<br>100% | | |
| Minimum independent baselines at each station | 4 | 4 | 4 | 3 | 2 |

Table 8. Minimum GNSS Occupation Time

| **Single Frequency** | | | |
|---|---|---|---|
| Length of Baseline | **< 5 Km** | **> 5 to <10Km** | **> 10 to <15km** |
| Static | 20 minutes | 20 to 50 minutes[1] | 50 to 75 minutes[1] |
| Fast Static @ 95% confident level | 15 minutes | 15 to 20 minutes | N.A. |
| **Double Frequency** | | | |
| Length of Baseline | **< 5 Km** | **> 5km to <15Km** | **> 15 to <50Km** |
| Static @ 95% confident level | 20 minutes | 20 to 50 minutes | 50-130 minutes[1] |
| Fast Static | 8 to 10 minutes[1] | 10 to 20 minutes[1] | N.A. |

Table 8. EDM Observation Requirements

| ORDER | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Number of days of observations | 2 | 1 | 1 | 1 | 1 |
| Number of sets of full measurements[1] | 4 | 4 | 2 | 1 | 1 |
| Move prisms between sets[2] | Yes | Yes | Yes | Optional | -- |
| Range of fine readings[3] | <2(5+d)mm | <2(5+d)mm | <2(5+d)mm | 7ppm | 15 ppm |
| Difference between two sets[3] | <2(5+d)mm | <2.5(5+d)mm | <2.5(5+d)mm | -- | -- |
| Difference between means of each day's measurements[3] | < 3(5+d)mm | -- | -- | -- | -- |
| Observation between 2 hours before local noon, and 2 hours before local sunset[4] | Yes | Yes | Yes | Optional | Optional |
| Atmospheric dial setting (where possible) | Zero | Zero | Zero | Optional | Optional |
| Allow minimum warm up time[5] | Yes | Yes | Yes | Optional | Optional |
| Thermometer type | Mercury in glass | Mercury in glass | Mercury in glass | Mercury in glass | Mercury in glass |
| Graduation Interval | < $1^{0}$ C | < $1^{0}$ C | < $1^{0}$ C | < $1^{0}$ C | < $1^{0}$ C |
| Estimate temperature to | $0.1^{0}$ C | $0.1^{0}$ C | $0.1^{0}$ C | $0.1^{0}$ C | $0.1^{0}$ C |
| Estimate pressure to | 0.3 hPa | 0.3 hPa | 0.3 hPa | 0.3 hPa | 0.3 hPa |
| Wet bulb readings or relative humidity readings | Yes | Yes | Yes | Optional | -- |
| Metrology at both ends of measured lines before and after measurements | Yes | Yes | Yes | At time of observations | -- |
| Reciprocal vertical angles[6] | Yes simultaneous | Yes simultaneous | Yes | Optional | Optional |
| National standard traceability of EDM | Yes | Yes | Yes | Yes | Yes |

Table 9. Electro-Optical EDM Reduction Procedures

| ORDER | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Additive constant correction | Yes | Yes | Yes | Yes | Yes |
| Reflector additive constant correction | Yes | Yes | Yes | Yes | Yes |
| Cyclic error correction | Yes | Yes | Yes | Yes | Optional |
| Frequency correction | Yes | Yes | Yes | Baseline | Baseline |
| Barometer correction | Yes | Yes | Yes | Yes | Optional |
| Thermometer correction | Yes | Yes | Yes | Yes | Optional |
| 1st velocity correction (atmospheric correction.) | Yes | Yes | Yes | Atmospheric dial | Atmospheric dial |
| Arc to chord correction (beam curvature correction.) | Yes | Yes | Yes | Over 5 km | Optional |
| 2nd velocity correction (dip correction) | Yes | Yes | Yes | Over 5 km | Optional |
| Chord to chord correction (combined slope & mean sea level) | Yes | Yes | Yes | Combined Scale Factor | Yes |
| 2nd chord to arc correction (geoidal chord to arc correction.) | Yes | Yes | Yes | Optional | Optional |
| Geoid to ellipsoid correction | Yes | Yes | Yes | Optional | Optional |

Table 10. Differential Levelling Observation Procedure

| ORDER | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Instrument leveled by "unsystematic" method [1] | Yes | Yes | Yes | Yes | Optional |
| "Leap-Frog" system of progression used [2] | Yes | Yes | Yes | Yes | Optional |
| Staff readings recorded to nearest | 0.01mm[3] . For digital levels take the mean of five with an indicated standard deviation. of 0.0002 or less. | 0.1mm. For digital levels as for Order 0 but with an indicated standard deviation. of 0.001 or less. | 0.1mm. For digital levels as for Order 1. | 1mm. For digital levels as for Order 1. | 10mm |
| Temperature recorded (When used). | Start, middle, finish and pronounced changes | At start and finish of each leveling run and at pronounced changes of temperature | | | -- |
| Maximum length sight | 30m. | 40m. | 60m. | 80m. | 100m. |
| Minimum ground clearance of line of sight | 0.5m. | 0.5m. | 0.5m. | 0.3m. | 0.2m. |
| Back-sight and fore-sight lengths to be equal within | 1% (Set out by taped measurement). | 2% | 3% | 4% | 5% |
| Observing times (Local Mean Time) | Any time atmospheric & weather conditions are fine | | Any time provided atmospheric conditions allow positive resolution of staff graduation. | | |
| Two-way leveling | Yes | Yes | Yes | Optional | Optional |
| Even number of instrument set-ups between bench marks. | Yes | Yes | Optional | Optional | Optional |
| Minimum number of holding marks used for temporary suspension of leveling | Not to be suspended | Not to be suspended | 2 | 2 | 1 |
| Minimum number of holding marks used for temporary suspension of leveling > 5 days | Not to be suspended | Not to be suspended | overlapping marks re-leveled within 2√d | overlapping marks re-leveled within 12√d | 1 |
| Maximum allowable misclosure (mm) of forward and reverse leveling runs [4] | 1.5√d | 1.5√d | 3√d | 12√d | 24√d |
| Minimum number of bench marks used to prove datum | 3 | 3 | 2 | 2 | 2 |
| Datum bench marks to be double leveled | Yes | Yes | Yes | Optional | Optional |
| Maximum misclosure (mm) on datum bench marks | 1.5√d | 1.5√d | 3√d | 12√d | 24√d |

Table 11. Differential Levelling Equipment Testing

| ORDER | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| System test prior to commencement (eg ISO, DIN or Princeton) | Yes | Yes | Yes | Optional | Optional |
| Maximum standard error in the slope of the line of sight as determined by the system test | Spirit level: 1"/2mm run Automatic or digital: 0.4" setting accuracy. | Spirit level: 1.5"/2mm run. Automatic or digital: 0.4" setting accuracy. | Spirit level: 4"/2mm run. Automatic or digital: 0.8" setting accuracy. | Spirit level: 10"/2mm run. Automatic or digital: 1.0"setting accuracy. | -- |
| Vertical collimation check (eg. Two-Peg Test) Frequency Maximum collimation error | Daily 2" or 0.3 mm over 30m. (Digital levels can "Store" the results) | Daily 2" or 0.8 mm over 80m. | Daily 4" or 1.5 mm over 80m. | Daily 10" or 4 mm over 80m. | As required 10" or 4 mm over 80m. |
| Level cross-hair verticality check | Yes | Yes | Yes | Yes | Optional |
| Staff calibration frequency | Immediately prior to commencement of leveling, and at 3 monthly intervals whilst in continued use. | | | Within 6 months of use. | Optional |
| Staff bubble verticality to be within | 5' [1] | 10' | 10' | 10' | 10' |
| Thermometers accurate to | 0.5°C | 1°C | 1°C | 1°C | Optional |