Rail Baltica
Coordinated by RB Rail

TECHNICAL SPECIFICATION

GEODETIC NETWORK ESTABLISHMENT FOR CONSTRUCTION STAGE OF RAIL BALTICA HIGH SPEED RAILWAY

RBDG-MAN-039-0102

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Revision	Issue Date	Author	Issue purpose	Description of changes
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1.1	28.12.2023	Georgios Papastamos Rait Leppik Andres Rüdja	Modifications	Corrections of terminology, definitions and abbreviations, improvement of technical information tables and drawings
1.2	02.12.2025	Rait Leppik Andres Rüdja Rokas Guzevičius	Modifications	Corrections of terminology, definitions and abbreviations, improvement of technical information incl. tables and drawings

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
EH2000	Estonian Height System
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
ETRF	European Terrestrial Reference Frame
ETRS	European Terrestrial Reference System
EUREF	IAG Reference Frame Sub-Commission for Europe
EUREF-EST97	Estonian Geodetic Reference System
EVRF	European Vertical Reference Frame
EVRS	European Vertical Reference System

Abbreviation	Definition
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
IAG	International Association of Geodesy
INS	Inertia navigation system
ISO	The International Organization for Standardization
LAMBERT-EST	Estonian Map Projection
LAS-2000,5	Latvian Height System
LAS07	Lithuanian Height System
Latvia TM	Latvian Map Projection
Lithuania TM	Lithuanian Map Projection
L-EST97	Estonian Planar Coordinate System
LKS-92	Latvian Geodetic Reference System
LKS-92 TM	Latvian Planar Coordinate System
LKS94	Lithuanian Geodetic Reference System
LKS94 TM	Lithuanian Planar Coordinate System
MNCP	Micro-network Control Point
PUO	Public Utility Organisations/Owners
RBDatum	The Geodetic Reference System dedicated to the Rail Baltica Project
RB-GRES	RB Geodetic Reference System
RB-HRES	RB Height Reference System
RB-MAP	RB Map Projection
RB-PCS	RB Planar Coordinate System
RBR	RB Rail AS
RoW	Right on the way-clear visibility from point to point
SSP	Supervision Service Provider – service provider awarded with an Agreement to conduct supervision services for construction of railway and geodesy network construction specified in this document

Abbreviation	Definition
TBM	Tunnel Boring Machine
TGMT	A Railway track geometry measuring trolley system
TS	Technical Specification
UELN	United European Levelling Network
EE	Republic of Estonia
LV	Republic of Latvia
LT	Republic of Lithuania

Definitions

The following terms are used throughout this document:

Term	Definition
Active Construction Zone	The active construction zone is the construction section defined by the Contract, in the width of the railway corridor, where any construction activity or movement of construction machinery takes place
BIM Model	3D models containing information (PIM & AIM)
Contractor	Service provider awarded with an Agreement to conduct Rail Baltica highspeed railway construction Services specified in this document including related construction works
Client	RB Rail AS and/or Implementing Bodies
Consultant	Service provider awarded with an Agreement to design Rail Baltica high speed railway with geodetic survey delivery
Contractor	Service provider awarded with an Agreement to construct Rail Baltica high speed railway with geodetic survey delivery
Country	Republic of Estonia/Republic of Latvia/Republic of Lithuania
Digital Format	For drawings, 2D or 3D, is a vector format (dwg, dgn, dxf, LandXML, .ifc, etc), for Tables or lists in xlsx, or ASCII format, Documents in Word, PDF or ascii format
Programme	Representation (including graphical) of the time schedule, tasks and milestones agreed between the Contractor 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	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) and corresponding geodetic measurements
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 AS, and/or Implementing Bodies and/or SSP

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.

2 General Terms

The Contractor 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.

3 Baltic Reference Systems

This paragraph identifies all data related to the existing situation of Geodetic and Height Reference Systems in the three Baltic states. The structure of the information presented is based on that applied in the Information and Service System for European Coordinate Reference Systems.

Related reference to follow: DG document No. RBDG-MAN-038 "GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTION STAGES OF RAIL BALTICA HIGH SPEED RAILWAY", 3. Baltic Reference Systems.

4 Rail Baltica Reference Systems

Related reference to follow: DG document No. RBDG-MAN-038 "GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTION STAGES OF RAIL BALTICA HIGH SPEED RAILWAY", 4. Rail Baltica Reference Systems.

5 Connection between Baltic and RB Reference Systems

Related reference to follow: DG document No. RBDG-MAN-038 "GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTION STAGES OF RAIL BALTICA HIGH SPEED RAILWAY", 5. Connection between Baltic and RB Reference Systems.

6 Structure Of RB Networks

Related reference to follow: DG document No. RBDG-MAN-038 "GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTION STAGES OF RAIL BALTICA HIGH SPEED RAILWAY", 6. Structure Of RB Networks.

7 Geodetic Network workflow

7.1 General instructions to the Contractor

3. The measurement works needs to be carried out by Contractor during the construction of the Rail Baltica Project and this task shall include the following:

   (a) updating of the topographical drawings and compilation of new ones, where required, with connection to the RB geodetic networks (Order 0-3 and MNCP);

   (b) establishment throughout the entire alignment length of a unified geodetic and levelling networks (in every Order) within RBDatum and connection with the already existing one (Figure 1);

   (c) establishment of Order 1-3/MNCP (and Order 0, if it's not implemented) geodetic and height networks connected to the RB primary geodetic network or if not available, then to the National Geodetic and Height Networks;

   (d) at the beginning of the construction activity and before the installation of the RB geodetic network benchmark, the Contractor must prepare a Network Design, which is approved by the Service;

   (e) regular geometrical control of the alignment, stations, bridges, platforms, tunnels, etc. after their construction;

   (f) regular control and updating of all CP geodetic networks according to Table 1, all raw and post-processed data and results are submitted to the Service for approval.

	RBDatum			
obligation of	RB Geodetic Network Order	consisting of	RB Vertical Network Order	obligation of
Designer Consultant	Order 0	CP0 benchmarks GNSS measurements Levelling Network adjustment	Order 0	Designer Consultant
Contractor	Order 1	CP1 benchmarks GNSS measurements Levelling Network adjustment	Order 1	Contractor
	Order 2	CP2 benchmarks Traverse measurements Levelling Network adjustment	Order 2	
	Order 3	CP3 targets Ttraverse measurements Network adjustment	Order 3	
	Micro Network	MNCP benchmarks GNSS and Traverse measurements Levelling Network adjustment	Micro Network	

Figure 1. Geodetic Network Obligation Status

Table 1. Geodetic Network Control Frequency

Network	Construction stage			Operational stage	
	before	active	after	before	active
CP0	once	once a year	once	once	once every two years
CP1	once	once a year	once	once	once every two years
CP2	once	quarterly	once	once	once a year
CP3	once	during daily usage*	on demand	on demand	on demand
MNCP	once	once a month	once	once	on demand

** CP3 will be checked by construction surveyor during daily usage.*

4. Nearest benchmarks of the geodetic and levelling networks (CP1, CP2) of the construction sections adjacent to the construction section under the Contract must also be included in the measurements. For details, see the chapters describing specific networks below.

5. If the establishment and measurement of geodetic benchmarks under the Contract is carried out section by section, the Contractor must also carry out the adjustment of the common network formed by the sections and submit the corresponding results in the final measurement report.

6. For Network Design of geodetic works, Service are expecting following information:
    (a) description of the geodetic measurement works need to performed (GNSS static, Total Station measurement, geometric levelling);
    (b) time schedule of the geodetic works;
    (c) overview scheme of designed network;
    (d) Reference System and Height System;
    (e) corrections and scale factors that are used;
    (f) information of the known base points;
    (g) list of the personnel who perform the works;
    (h) a list of the instruments to be used with their valid calibration certificates, calibration intervals are described in RBDG-MAN-038, Annex 1;
    (i) description of the calculations and adjustments that will be done;
    (j) description of the new CP or MNCP points, including a location sketch and benchmark type;
    (k) estimated installation time schedule, which must be submitted to the Service at least 1 week before the start of installation activities on site, the Geodesy Expert from RB RAIL AS or from IB or SSP must be included at least for 1 working day to follow the geodetic benchmark installation process on site.

7. Each RB geodetic control point is assigned a unique point number (Table 2), which depends on its location and hierarchical level. RB Geodetic point numbers increase from north to south. The numbering system allows each DPS to contain a maximum of 999 points in each point class (CP0 is not included).

8. The numbering will be provided by the Client.

9. If abbreviated numbers are used in the measurement, the report must contain a table with both the measurement numbers and the numbers of the points compiled according to the principles given in Table 2.

10. For all geodetic works, the Contractor is obliged to obtain the approval of the Service and to provide updates according to the agreement.

11. All data (raw data, coordinate files, drawings) shall be stored in digital form and shall be transmitted to the Client CDE in an agreed manner, provided it is requested by the Client and at a frequency has been mutually agreed upon.

12. For all geodetic works required for the design and construction of the Project, RBDatum shall be used, if available. If not available, then National systems will be used.

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

14. The Contractor is responsible for verifying the adequacy and completeness of any information provided to him, related to every aspect of the Project. Moreover, the Contractor is responsible to update and supplement all drawings and compile new drawings wherever required. All topographical survey, geodetic works, alignments, updating of drawings, compilation of new drawings, etc., shall be performed with the exclusive use of terrestrial methods.

15. All geodetic measurements, as well as the calculations, the results, and the drawings for all the geodetic works herein shall be submitted for approval to the Service in digital form and shall be signed by the Contractor.

Table 2. Point numbering

Country	Estonia	Latvia	Lithuania
Every DPS contain all level of point classes with maximum possible amount of points	CP0 – approx. 117 points CP1 – 999 points CP2 – 999 points CP3 – 999 points MNCP – 999 points TEMP – 999 points		
Country code	EE	LV	LT
DS code	1 – 2 – 3	1 – 2 – 3 – 4	1 – 2 – 3 – 4 – 5 – 6
DPS code	1 – 2 – 3 – 4 – 5	1 – 2 – 3 – 4 – 5	1 – 2 – 3 – 4 – 5 – 6
Control point level *TEMP - temporary point in CP and MNCP measurements	CP0 CP1 CP2 CP3 MNCP TEMP*		
Point sequence number in every DPS (except CP0)	001 – 999		
All assigned numbers are written with a hyphen in the following form, for example:	LV-CP0-39 (CP0 No 39, locating in Lavia) LV22-CP1-039 (CP1 No 39, locating in Latvia in DS2, DPS2) LV22-CP2-039 (CP2 No 39, locating in Latvia in DS2, DPS2) LV22-CP3-039 (CP3 No 39, locating in Latvia in DS2, DPS2) LV22-MNCP-039 (MNCP No 39, locating in Latvia in DS2, DPS2) LV22-TEMP-039 (temporary point No 39, locating in Latvia in DS2, DPS2)		
A special letter will be added for leveling markers in case of pillar monument	U – upper levelling marker L – lower levelling marker		
For example:	LV22-CP2-039U (CP2 no 39 upper levelling marker, locating in Latvia in DS2, DPS2)		

If an additional CP needs to be added between existing benchmarks, then an additional letter is added with an increasing number starting from the previous CP number on the northern side	A – Additional 1 – first point 2 – second point
For example:	LV22-CP1-039A1 (additional point 1 between CP1 points No 39 and No 40 locating in Latvia in DS2, DPS2)
If the CP needs to be replaced (either one or both markers in the case of pillar), an additional letter is added with the modification number	R – Replaced 1 – number of first replacement 2 – number of second replacement
For example:	LV22-CP1-039R1 (CP1 No 39 has replaced first time by new point, locating in Latvia in DS2, DPS2)

16. During the design and establishment phase, the Contractor must take into account the existing design of the Project, including topographical information. Corresponding information is provided by the Service.

17. The locations of the installed CP1, CP2 and MNCP benchmarks or their designed locations approved by the Service must be taken into account in all following design and construction stages. All subsequent construction activities within a radius of 2 m from the benchmark (if part of the radius is outside the railway property, the boundary of the property is considered to be the boundary of that part) must be coordinated with the Service.

18. The planning of the alignments and measurements (as well as their implementation) shall always be carried out based on hierarchy, starting from the general drawings which shall contain the reference data and the boundaries of the detailed drawings, to avoid any omissions and discrepancies on the detailed drawings.

7.2 Method Statement – Network Design

19. For all the above and before the commencement of the Project's construction works, the Contractor is obliged to submit to the Service for approval the Methodology for execution of all Geodetic 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. Content of Network Design for Contractor.

No.	Content topics
1.	General part - Introduction
1.1	Summary description of the project
1.2	Contractual obligations
1.3	Staffing of the geodesy 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, precision
2.8	Software
2.9	Maintenance
3.	Theoretical data
3.1	General description
3.2	Requirements
3.3	Software
3.4	Submittals
3.5	Forms
3.6	Approvals
3.7	Files
4.	Measurements
4.1	General description

No.	Content topics
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 Service
6.1	General description
6.2	Templates of electronic files
6.3	Forms
6.4	Frequency
6.5	Storing
6.7	Archiving

20. All the above shall be inspected and approved by the Service within regular time periods to be agreed upon, based on the progress of the construction works.
21. The completeness of the measurement 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 construction works. Therefore, the submitted methodology must be approved by the Service, and any eventual comments must be considered by the Contractor.
22. The recording of the results and the archiving is performed based on the Project's segmentation into Sections, as specified in advance. Data shall be provided ccording

to RB Rail Design Guideline requirements. It is evident that the structure of the documents' archiving system must be accompanied by the appropriate digital data format for the purpose of the correct and immediate data exchange with Service.

7.3 Primary Network CP0

Related reference to follow: DG document No. RBDG-MAN-038 "GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTION STAGES OF RAIL BALTICA HIGH SPEED RAILWAY", 7.3 Primary Network CP0.

7.4 Primary Network CP1

7.4.1 CP1 Geodetic Network

23. The CP1 Geodetic Network is the connection between the CP0 Geodetic Network and the denser CP2 Geodetic Network. Each one of the subject benchmarks shall necessarily be mutually visible with its immediate previous and subsequent CP2 benchmark along the alignment.
24. The CP1 network section to be established must be connected to at least three CP0 points (preferably more), if available. If these are not available, points of the National Geodetic Network and/or CORS stations must be used instead.
25. CP1 control benchmarks shall be established by the Contractor along the railway corridor at intervals of approximately 1.5 - 2.0 km (see RBDG-MAN-038, Figure 2), and location must remain inside the protective fence but far enough from the objects of the RB railway infrastructure.
26. The locations for CP1 benchmarks should be at solid ground, with 10° from horizon clear sky view (no trees, structures, or other obstacles) and there are no sources of electromagnetic radiation nearby. The location of these benchmarks shall be defined in cooperation with the Service.
27. The locations of all CP1 benchmarks must be suitable for high precision static GNSS measurements and high-precision geometric levelling.
28. When selecting the location of the benchmarks, it must be ensured that a GNSS network formed by triangles can be established between them.
29. For CP1 benchmark construction specifications see RBDG-MAN-038, Annex2. Depending on the soil characteristics, due to location or regional restrictions, Contractor may propose alternative benchmark type for approval in Network Design.
30. Measurements of this order network shall be based on the Relative Static GNSS measurement method. The above network shall be linked with neighbouring points of the CP0 network.

31. All measurement methods other than the Relative Static GNSS measurement method are prohibited.

32. When planning Relative Static GNSS measurements, relevant planning software must be used to determine expected DOP values and number of visible satellites. The corresponding graphs and the actual values during measurements must be submitted with the final report.

33. Magnetic storm warnings must be checked before the measurements and the corresponding graphs must be presented in the measurement report.

34. CP1 Geodetic Network (Figure 2) measurements shall be carried out according to the following instructions:

    (a) measurements are designed in such a way that only so-called independent GNSS vectors belong to the network - in each session where "n" number of GNSS receivers participate, there are "n - 1" number of independent GNSS vectors;

    (b) wherever possible, independent vectors must form a network of triangles;

    (c) GNSS antennas are oriented towards the north during measurements;

    (d) the cut-off angle of GNSS signals is 10 degrees;

    (e) the recording interval of GNSS signals is 15 seconds;

    (f) a wooden tripods are used for measurements;

    (g) rotatable centering devices equipped with cylindrical plummets, the mean square error of centering of which not exceed ±0.5 mm, are used for measurements;

    (h) in the event that several consecutive measurement sessions are performed on a same benchmark, the GNSS antennas are re-centered between sessions and different sets of GNSS measurement equipment are used where possible;

    (i) in the course of GNSS measurements, field reports are filled in, containing point number, point name, session date (format: yymmdd), session number (consecutive sessions of one day are denoted by A, B, C, etc), session start time, session end time, GNSS receiver serial number, GNSS antenna serial number, operator's name, operator's signature, measured antenna height with information whether the slant or vertical height was measured, and to which antenna element it was measured;

    (j) the PDOP value should be less than 5;

    (k) the duration of GNSS measurement sessions is at least 1.5 hours, and at least 2 measurement sessions are performed on the mark to be determined; for distances longer than 10 km (between CP1 and CP0, or National Network benchmarks or CORS), sessions of at least 4 hours are recommended; for distances exceeding 15 km (between CP1 and National Network benchmarks or CORS if CP0 is not available), sessions of at least 6 hours are recommended.

35. The CP1 network is generally built in sections according to the progress of railway construction. For such sections, a connection must be established between them so that at least one CP1 benchmarks from each neighbouring section network is included in the measurements.

36. By combining data from sections during joint adjustment, seamless connectivity of sections and a unified solution for the entire network must be ensured.

37. If the section to be established is separate, does not border previously established sections, at least three benchmarks of the given section are measured using the GNSS method, taking into account the geometry and horizon requirements of the CP1 network.

38. In order to achieve the desired precision estimates, it is necessary to follow the following criteria:

    (a) the GNSS instruments must have the ability to receive at least signals from the GPS, Galileo and GLONASS satellite systems;

    (b) the receiver performance, precision, for static GNSS measurements shall be for the horizontal component of the coordinates ±3 mm + 0.1 ppm or better and for the vertical component ±5 mm + 0.5 ppm or better;

    (c) in the measurements GNSS antennas, whose multipath reduction properties, antenna sensitivity, mounting accuracy of antenna elements, etc. are in accordance with the requirements of high-precision GNSS measurements, are used; Choke Ring antennas are strongly recommended;

    (d) GNSS antenna phase centre precision must be ±2 mm or better;

    (e) the absolute calibration parameters of the antenna type must be known.

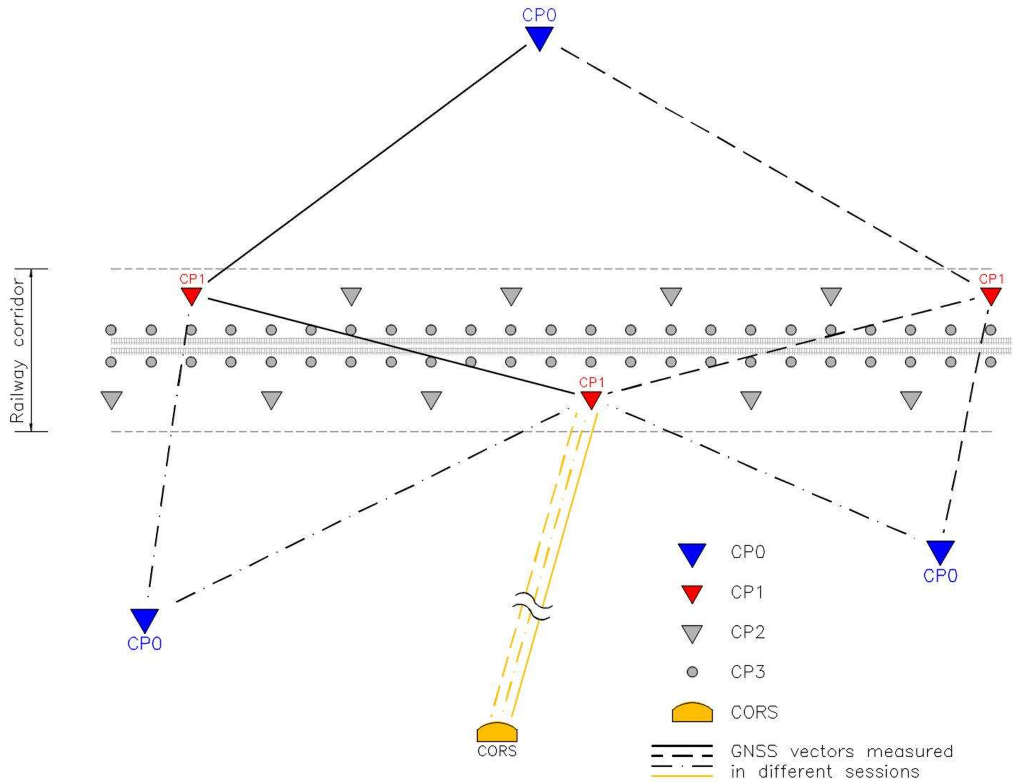

Figure 2. A basic example of a CP1 network fragment

39. The following should be considered when processing GNSS measurements:

(a) GPS, Galileo and GLONASS satellite navigation system signals are used in GNSS vector calculation;

(b) in the GNSS data processing, the final, precise satellite orbits and clock corrections are used;

(c) in the Network Design and Report, the ionospheric and tropospheric models used and the way they are implemented are described;

(d) the linear combinations used in vector calculations are chosen based on the lengths of the vectors;

(e) when different type of GNSS antennas are used, constant and GNSS signal direction-dependent corrections of their phase centres are taken into account using the calibration parameters given in the ANTEX (Antenna Exchange Format) file of the International GNSS Service (IGS);

(f) during vector calculations, the ambiguities are solved;

(g) the network formed from GNSS vectors is adjusted using the least squares method;

(h) adjustment calculations are carried out in the three-dimensional Cartesian coordinate system;

(i) statistical tests (e.g. F-test, W-test, T-test, etc) are used to identify gross and systematic measurement errors and to assess the reliability of the results;

(j) final coordinates and ellipsoidal heights must be given showing to 3rd decimal.

(k) The standard deviation of the planar position of the CP1 points obtained from the least squares adjustment must not exceed ±6 mm and the standard deviation of the ellipsoidal heights obtained from the least squares adjustment must not exceed ±6 mm.

40. The coordinates and ellipsoidal heights shall be given based on the National coordinate system and the RBDatum if available, with the respective standard deviations.

41. The information about GNSS system and the software to be used shall be submitted to the Service for prior approval.

42. The identification of benchmarks of the network shall be made through an appropriate method, in a way, ensuring their preservation during the construction of the Project, as well as for their future use, approved by the Service.

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

44. During the construction period, the Contractor is responsible to maintain the benchmarks of the above network, and in case wear or obstacles is observed, the Contractor shall proceed to the replacement of the affected points and their incorporation into the geodetic network upon its re-measurement and re-calculation.

45. The above network shall be checked periodically (Table 1), in time intervals to be agreed with the Service, while in case of disagreement among the results, the network shall be re-adjusted.

46. Descriptions of benchmark construction and benchmark installation, measurement data (incl. raw data), descriptions of the measurement and calculations methods, network scheme, results (geodetic coordinates must be given as 8 decimal degrees, and planar coordinates and ellipsoidal heights must be given showing to 3rd decimal) and their precision estimates, measures to ensure the preservation of benchmarks, description of the methods of marking the benchmarks used, and benchmark location descriptions shall be submitted to the Client/Service in a digital form.

7.4.2 CP1 and CP2 Levelling Network

47. The CP1 Levelling Network will be established at the CP1 and CP2 benchmarks.

48. CP1 and CP2 levelling network is generally established section by section according to the progress of railway construction. For such sections, a connection must be established between them so that at least three closest benchmarks from each neighbouring section networks (this may also include initial benchmarks if the connections to them are re-levelled, in this case at least two benchmarks from each neighbouring section networks must still be included) are included in the measurements. By combining data from sections

during joint adjustment, seamless connectivity of sections and a unified solution for the entire network must be ensured.

49. This network will be measured by means of geometrical double-run foot levelling and will be linked with CP0 Levelling Network or State Levelling Network; moreover, it shall, if possible, consist of a sufficient number of loops to ensure the maximum possible reliability in the adjustment phase.

50. The geometric levelling lines shall be fully constrained on both ends to the levelling benchmarks of the CP0 Levelling Network or State Levelling Network.

51. A massive wooden tripod is used for levelling, the leg lengths of which are not adjustable.

52. The instruments to be used shall be high precision digital levels, with a precision not worse than ±0.3 mm per 1 km double run, along with their corresponding invar rods to achieve the precision required. Instrument specifications shall be submitted to the Service for approval.

53. The maximum length of sight must not exceed 40 meters, and back-sight and fore-sight length at the station must not differ by more than 0.5 m, and the sum of the differences in the section cannot exceed 1.0 m.

54. Levelling order in every station:
    (a) odd numbered station BFFB (back-fore-fore-back);
    (b) even numbered station FBBF (fore-back-back-fore).

55. To achieve quality measurements bad weather conditions such as heat haze, heavy wind and rain or fog, should be avoided when making observations.

56. The maximum allowable difference between forward and backward levelling run in a sections is 1.5 mm$\sqrt{d}$ [km]. In case of higher discrepancies, measurements shall be repeated.

57. Height differences at station must not vary by more than 0.2 mm.

58. Additional requirements for the equipment and methodologies are described in RBDG-MAN-038, Annex 1.

59. The heights of the points shall be calculated using the least squares adjustment method.

60. The standard deviation of the CP1/CP2 point heights obtained from the least squares adjustment must not exceed ±2 mm.

61. The above network shall be checked periodically, in time intervals to be agreed with the Service (in any case not greater than one-year intervals), while in case of disagreement among the results, the heights of the benchmarks must be updated (Table 1).

62. Measurement data (incl. raw data), descriptions of the measurement and calculation methods, network scheme, results (heights displayed with 3 decimal places) and their precision estimates, measures to ensure the preservation of benchmarks and description of the methods of marking the benchmarks used and benchmark location descriptions

unless they are described when establishing CP1 and CP2 geodetic networks shall be submitted to the Client/Service in a digital form.

7.5 Secondary Network CP2

7.5.1 CP2 Geodetic Network

63. The secondary geodetic control network CP2 shall be implemented following the densification of the Primary CP1 control network at locations mutually visible, fairly close to the alignment (not more than 40 m away) in order to be used for the Project construction, at intervals of 400 m and location must remain inside the protective fence. Network shall connected at least two points of the Primary Network. Benchmark locations shall be defined in communication with the Service.

64. For CP2 benchmark construction specifications see RBDG-MAN-038, Annex 2. Depending on the soil characteristics, due to location or regional restrictions, Contractor may propose alternative benchmark type for approval in Network Design.

65. CP2 points shall be measured from CP1 (Figure 3):

    (a) by using Total Station measurement in the network mode, for superstructure measurements (especially determining rail geometry) only full constrained network, constrained at both ends from CP1 shall be used;

    (b) the standard deviation of the planar position of the CP2 points obtained from the least squares adjustment must not exceed ±4 mm.

66. Following requirements shall be met:

    (a) checks and adjustments must be performed on the Total Station before the commencement of measuring works and the results of the checks and adjustments must be presented in the measurement report;

    (b) each point must be measured from at least two different stations, single measurements are not allowed;

    (c) altogether 4 full sets of measurements using the repetition method at each station shall be done; if the sets closure is higher than the given tolerance of 6'' between half sets and 3'' between sets, the extra round of measurements shall be made;

    (d) to achieve quality Total Station measurements, bad weather conditions such as heat haze, heavy wind and rain or fog, should be avoided when making observations.

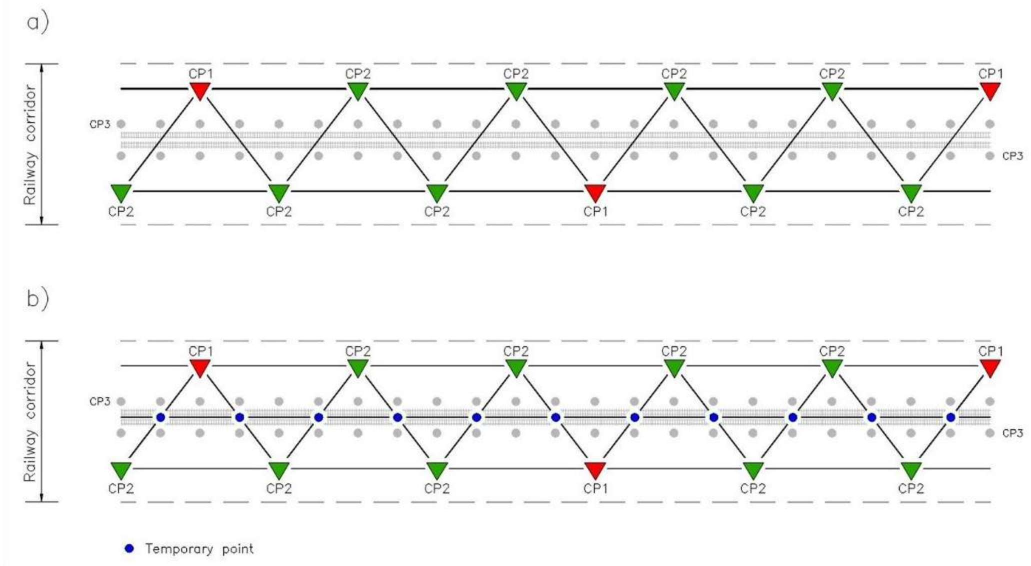

Figure 3. A basic example of a CP2 network fragment: a) primary solution, b) exceptional solution in case the primary solution is no longer possible due to a high embankment, etc.

67. CP2 network is generally established section by section according to the progress of railway construction. For such sections, a connection must be established between them so that at least three closest benchmarks from each neighbouring section network are included in the measurements. By combining data from sections during joint adjustment, seamless connectivity of sections and a unified solution for the entire network must be ensured.

68. The Contractor is responsible for the maintenance, the periodic checking and the replacement and re-definition (if necessary) of the points of the secondary network.

69. The angular precision of the Total Station to be used in the measurement of the network shall be ≤ 1″ (0.3 mgon) and the distance precision (incl. Total Stations and circular prisms of corresponding precision) of ±(1 mm+2 ppm) or better; the information about the instruments shall be submitted to the Service for approval.

70. The Contractor shall be in constant communication with the Service and submit the descriptions of benchmark construction and benchmark installation, measurement data (incl. raw data), descriptions of the measurement method and calculations, network scheme, results (displayed with 3 decimal places), measures to ensure the preservation of benchmarks, description of the methods of marking the benchmarks used, and benchmark location descriptions in a digital form.

71. The network to be developed for the alignment needs of the basic project and is within the construction zone of the Works must be checked regularly (Table 1).

72. To separate the evaluation of observations and known stations, the least squares adjustment of a network is usually subdivided into two separate steps or phases:

    (a) free network adjustment;

(b) constrained adjustment.

73. Statistical tests (e.g. F-test, W-test, T-test, etc) are used to identify gross and systematic measurement errors and to assess the reliability of the results.

74. The coordinates shall be given based on the National coordinate system and the RBDatum if available, with the respective standard deviations.

75. The identification of benchmarks of the network shall be made through an appropriate method, in a way, ensuring their preservation during the construction of the Project, as well as for their future use, approved by the Service.

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77. .

7.5.2 CP2 Underground Networks

78. As far as underground works are concerned, such as tunnels or stations, it is required to establish an underground geodetic control network which shall use geodetic network on the surface as a reference network.

79. The connection to the geodetic network (Figure 4) on the surface shall be carried out with the establishment of extension of a Order 2 geodetic network which will be connected with at least two points of the Order 1 and/or Order 2 geodetic network at both ends.

80. The Order 2 underground horizontal network shall have the appropriate length of sides to fit the characteristics of the tunnel alignment (not larger than 50 m). The marking of the control points of this network shall be permanent, so that this marking be secured against any eventual damage due to the execution of construction works.

81. The expansion and densification of the underground network shall be implemented each time a new point is established and measured. For this reason, at least two points of the geodetic network shall be used; however, these points shall be checked at regular time intervals from the geodetic network.

82. After the completion of the tunnel excavation works, the underground network must be measured once more by means of connections on both ends (of the constructed tunnel) with at least four (4) points of the geodetic network, located in the areas of the two portals, with measurements and calculations of the same period.

83. The angular precision of the Total Station to be used in the measurement of the network shall be ≤ 1" (0.3 mgon) and the distance precision (incl. Total Stations and circular prisms of corresponding precision) of ±(1 mm+2 ppm) or better; the information about the instruments shall be submitted to the Service for approval.

84. Adjustment of the underground geodetic (and/or trigonometric) network is carried out by the appropriate software using the least squares methodology.

85. Following requirements must be met:

(a) the standard deviation of the planar position obtained from the least squares adjustment must not exceed ±4 mm;

(b) altogether 4 full sets of measurements using the repetition method at each station shall be done, if the sets closure is higher than the given tolerance of 6'' between half sets and 3'' between sets, the extra round of measurements shall be made;

(c) to achieve quality measurements bad weather conditions such as heat haze, heavy wind or fog, should be avoided when observations are made.

86. The method used for the measurement and processing, the software and the instruments must be approved by the Service.

87. In case of TBM use, the underground network shall be established as mentioned above, while its densification for the TBM alignment shall be affected through a network whose sides shall not be greater than 50 m on straights and 35 m on curves.

88. This network shall be controlled on a regular basis and the coordinates of the points shall be re-calculated, if necessary, in communication with the Service.

89. The establishment of the underground levelling control network as reference network is based on the points of the Order 1 and Order 2 levelling network, which are checked by the Primary levelling network for possible deformations due to construction works during the same period. The Order 2 underground network shall be established based at a minimum of two benchmarks within the tunnel or the station. The benchmarks to be established shall be used in the establishment of a network consisting in levelling traverses along the tunnel or the station.

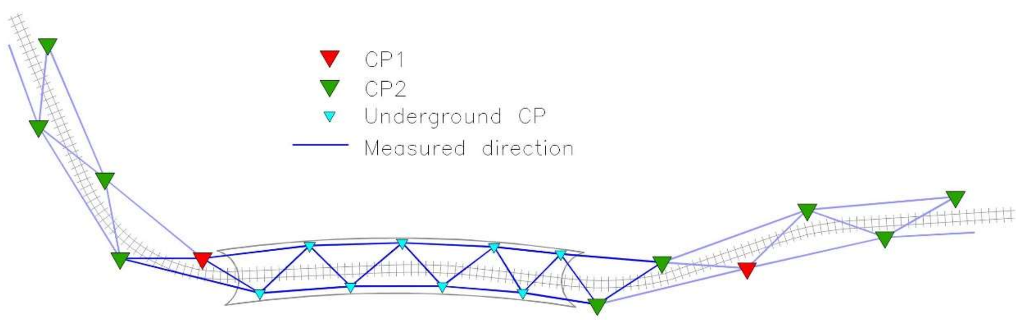

Figure 4. Basic scheme of the Underground Network

90. The measurement of the levelling lines shall be established by means of open double-run geometrical levelling lines, fully constrained on both ends.

91. The instruments to be used shall be high precision digital or optical levels, with a precision not worse than ±0.3 mm per 1 km double run, along with their corresponding invar rods to achieve the precision required. Instrument specifications 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.

92. Underground benchmarks shall be established approximately every 100 m which depend of the curvature of the alignment and visibility and their marking shall be permanent.

93. For the levelling methodology, the corresponding requirements of CP2 must be followed.

94. The information about underground Levelling Network benchmark type, the method of measuring, the instruments, and the software to be used shall be submitted to the Service for approval before the commencement of the works.

95. The underground Levelling Network shall be adjusted using the least squares method.

96. The standard deviation of the heights of the underground CP2 points obtained from the least squares adjustment must not exceed ±2 mm.

97. The identification of the benchmarks of the levelling network shall be permanent and ensure their preservation both during the construction of the Project and for future use.

98. During the construction period, the Contractor is responsible for maintaining the benchmarks of the above network, and in case of damage or obstacles, the affected marks should be replaced and re-integrated into the network through its re-measuring and re-calculation.

99. The network shall be checked periodically, see Table 1, or at time intervals agreed with the Service, and if the results disagree, the network shall be re-adjusted.

100. Measurement data (incl. raw data), descriptions of the measurement and calculation methods, network scheme, results (heights and planar coordinates displayed with 3 decimal places) and their precision estimates, measures to ensure the preservation of benchmarks, and benchmark location descriptions shall be submitted to the Service in digital form.

7.6 CP3 Geodetic Network

101. CP3 benchmarks are for high precision construction and maintenance of track.

102. CP3 will be located on the catenary masts (Figure 5). The height of the benchmark mounting hole from the bottom of the mast should be 1.2 m. The diameter of the hole must correspond to the installation diameter of the M8 bolt and must be ensured even after the mast is covered with a coating.

103. The mounting hole must be located on the side of the mast that remains in the direction of the rails after mast’s installation.

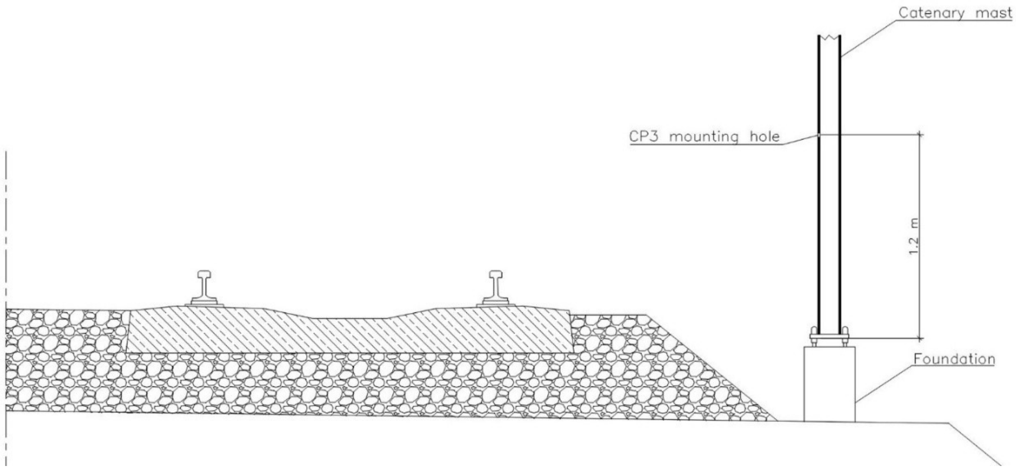

Figure 5. Typical location of the CP3 benchmark, units mm

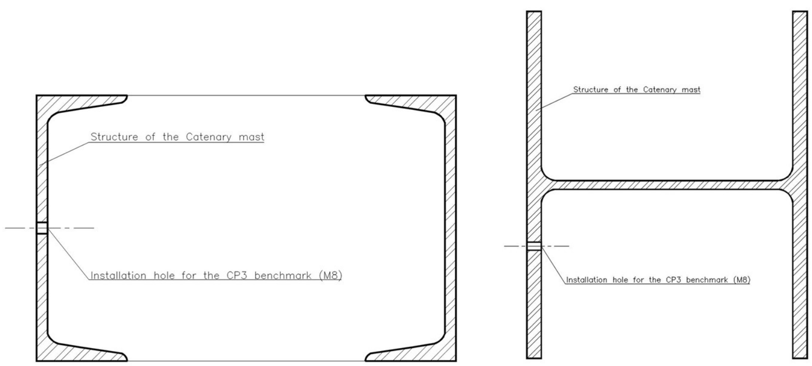

Figure 6. Examples of the locations of the CP3 benchmark installation holes on the catenary mast depending on the mast type selected

104. The basic specifications pertaining to the establishment of CP3 network (Figure 7) are the same as for CP2. Additional requirements for methodology and higher precision are described as follows:

(a) Total Station measurement, full constrained 3D (horizontal and vertical) network, from CP1 and CP2 shall be used;

(b) The standard deviation of the planar position of the CP3 points obtained from the least squares adjustment must not exceed ±2 mm and the standard deviation of the heights obtained from the least squares adjustment must not exceed ±1 mm;

(c) the Total Station used for measurements must correspond to that required for CP2;

(d) before measurement works, checks and adjustments of the Total Station must be performed, and the results must be presented in the report of measurement works;

(e) each point must be measured from at least two different stations (see Figure 7, single measurements are not allowed;

(f) altogether 6 full sets of measurements using the repetition method at each station shall be done, if the sets closure is higher than the given tolerance of 10'' between half sets and 5'' between sets, the extra round of measurements shall be made;

(g) to achieve quality measurements, bad weather conditions such as heat haze, heavy wind and rain or fog, should be avoided when observations are made.

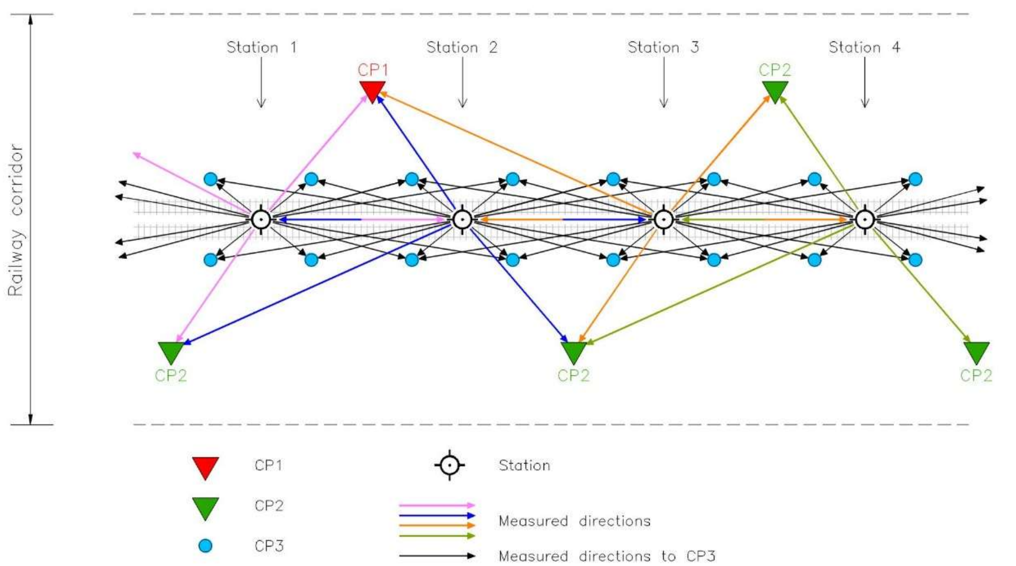

Figure 7. Basic structure of the CP3 Control Network

105. The Contractor shall coordinate the prism mounting devices and type of prisms with the Service prior to their installation to ensure their compatibility with the track geometry measurement systems.

106. Measurement data (incl. raw data), descriptions of the measurement and calculation methods, network scheme, results (displayed with 3 decimal places) and their precision estimates, description of the methods of marking the benchmarks used, and benchmark location descriptions shall be submitted to the Service for approval in a digital form.

7.7 Micro-network Control Point (MNCP)

107. Micro-network control points (MNCP) shall be placed close to structures of high construction standards (e.g. bridges, tunnels, stations, overpasses, ecoducts, depots, terminals etc) but outside the influence zone of the structure. Micro-networks can be used for Deformation Monitoring as well.

108. Micro-networks have increased density of control points around each structure and are of high precision internal geometry. The location of each MNCP should offer clear line of sight to the structure and to as many as possible other MNCPs, to strengthen the network.

Specifications of type of benchmarks are presented in RBDG-MAN-038. Depending on the characteristics of soil and locational or regional restrictions, Contractor may propose additional benchmark type for approval in Network Design.

109. MNCP points can be directly connected with the CP0, CP1 and CP2 points.

110. Micro-network benchmark locations shall be defined in communication with the Service. It shall depend on at least two points of the CP0 or CP1 or CP2 networks (Figure 8).

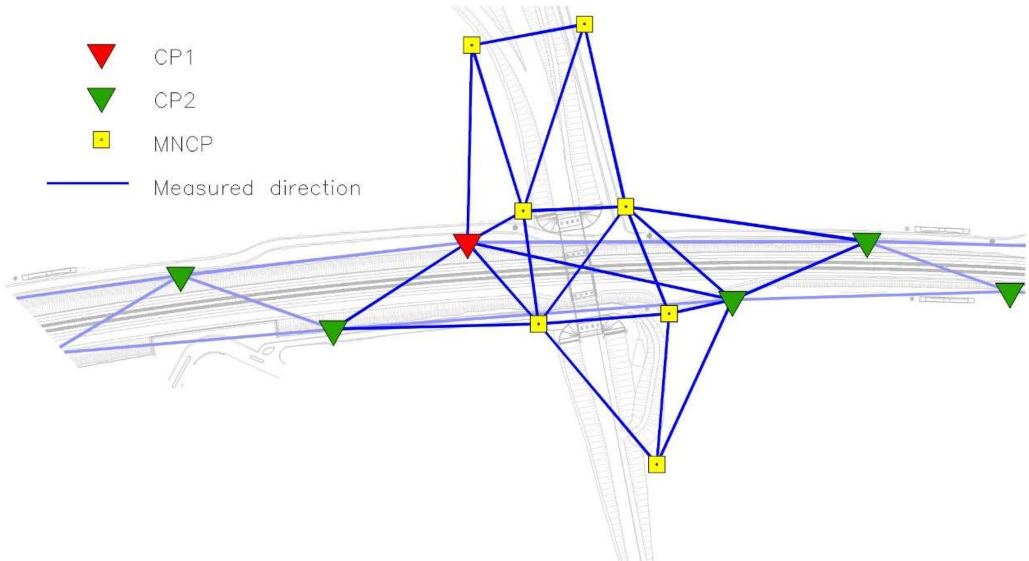

Figure 8. Basic scheme of a Micro Network

111. The following requirements shall be followed:

(a) Total Station measurement and full constrained 3D (horizontal and vertical) network from CP0, CP1 and CP2 are used;

(b) altogether 4 full sets of measurements using the repetition method at each station shall be done, if the sets closure is higher than the given tolerance of 6'' between half sets and 3'' between sets, the extra round of measurements shall be made;

(c) to achieve quality measurements bad weather conditions such as heat haze, heavy wind and rain or fog, should be avoided when observations are made.

112. Heights are determined based on the levelling specifications of CP1 and CP2, taking into account the differences given in Annex 1 of RBDG-MAN-038.

113. The angular precision of the Total Station to be used in the measurement of the network shall be ≤1" (0.3 mgon) and the distance precision (incl. Total Stations and circular prisms of corresponding precision) of ±(1 mm+2 ppm) or better; the information about the instruments shall be submitted to the Service for approval.

114. The standard deviation of the planar position of the MNCP points obtained from the least squares adjustment must be ±4 mm and the standard deviation of the heights obtained from the least squares adjustment must be ±2 mm.

115. MNCP points to be developed for the alignment needs of the basic project, which are within the construction zone of the Works, must be regularly checked (Table 1).

116. To separate the testing of observations and known stations, the adjustment of a network is usually subdivided into two separate steps or phases:

   (a) free network adjustment;

   (b) constrained adjustment.

117. Marking of the network benchmarks shall be made in a way that the risk of their destruction is minimal, the appropriate method is approved by the Service.

118. The Contractor is responsible for the maintenance, the periodic checking and the replacement and re-definition (if necessary) of the MNCP points.

119. For the network established, the Contractor shall submit to the Service the field measurements, calculations, resulting coordinates and heights showing to 3rd decimal and their precision estimates, network schemes, descriptions and securing of the benchmarks in a digital form.

8 Construction Measurements

8.1 General instructions to the Contractor

120. The measurement works needs to be carried out by Contractor during the construction of the Rail Baltica Project and this task shall include the following:

   (a) the Contractor is responsible for verifying the adequacy and accuracy of any information that is forwarded/provided to him relating to the Project;

   (b) prior to any of geodetic measurement for construction purpose (except the ground preparation works, like deforestation, topsoil removal, backfills and lower base layers) where construction or installation tolerance is more than ±5 cm and works carried out by RTK-GNSS, the Contractor has to submit a Network Design and Measurement Report of geodetic network works to the Service for approval; IB-s may, due to the specification of the work, still require the immediate submission of the Network Design and Measurement Report before starting any geodetic works on construction site.

   (c) to carry out geodetic (network) works on site, the contractor must use a surveyor with the appropriate competence and submit documents proving the competence.

8.2 Stakeout surveying

121. The Contractor shall carry out all geodetic measurement works related to the setting out and the execution of all Rail Baltica Projects, shall process the field data, shall make the necessary calculations and shall submit any drawings required for the completion of the project.

122. All the above works, which shall be based on the Methodology of Measurement Works described in Network Design, shall based on the RBDatum or if not available, then to the National Geodetic and Height networks.

123. The Contractor shall be responsible for the correct and proper implementation of all theoretical lines, dimensions and gradients required for the construction of the project, in accordance with the construction and/or contractual documents.

124. The Contractor's instrumentation and the entire measurement equipment shall be accurate, suitable for the measurements required, in compliance with the recognized technical standards (ISO 17123[1]) and in proper condition, properly adjusted and calibrated, while it shall be submitted to the Service for approval, before the commencement of each phase of the works.

125. All original data and records shall be stored and filed by the Contractor based on the project's segmentation and in such a way to be easily accessible and comprehensible by the Service. The Service or its designated representatives shall be entitled to make use and to always check the above data. The results of the measurements and calculations, as well as the calculations themselves shall be always at the Service's disposal, in a digital form.

126. At any time during the execution of the Project, the Service reserves the option to check the overall geodesy work (such as field data, measurements, lines, grades, points, markers,

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[1] **ISO 17123** - consists of the following parts, under the general title Optics and optical instruments — Field procedures for testing geodetic and surveying instruments:

— Part 1: Theory

— Part 2: Levels

— Part 3: Theodolites

— Part 4: Electro-optical distance meters (EDM measurements to reflectors)

— Part 5: Total stations

— Part 6: Rotating lasers

— Part 7: Optical plumbing instruments

— Part 8: GNSS field measurement systems in real-time kinematic (RTK)

— Part 9: Terrestrial laser scanners

Annexes A, B and C of this part of ISO 17123 are for information only.

and drawings) or any part thereof. Regardless of whether the Service proceeds on this option or not, the Contractor shall not be released from his responsibility for the accuracy and the correctness of the geodetic works. The Contractor shall be responsible for any lines, dimensions, grades, points, or measurements not complying with the applicable construction tolerances as well as for any resultant defect in the performance of Work. The Contractor shall perform all additional measurements required in view of correcting errors resulting during the construction works and /or identified by the Service's review in relation to the topographical surveying work or any part thereof.

127. Calculations, triangulations, and field measurements, including measurements of the main control lines in view of determining alignment of major structural elements shall be performed at the accuracy degree required by the construction Contract.

128. If the Contractor makes use of geodetic control points, which have been established either by himself or by any Contractor before him, he shall be obliged to verify the accuracy and correctness of the measurement data provided to him and accept the responsibility for all measurements in relation to the above.

129. The most important surveying principles during construction, that Contractor shall respect:

(a) RTK can be used for staking out or for As-built surveying for earthworks (deforestation, top-soil removal, cuts, fills, consolidation, dumping or loaning areas or queries, stockpiles of materials) and in general wherever a construction or installation tolerance is more than ±5 cm. The performance and accuracy of RTK device must be checked daily on the valid RB Geodetic and Levelling network benchmark or on the National Geodetic Network benchmark (if RB CP network is not available) before and after geodetic measurement works;

(b) for staking out and controlling structures like, buildings, stations, platforms, bridges, overpasses, underpasses, ditches- and in general whatever is related with water flow, superstructure, and rails installation, and in general wherever a construction or installation tolerance is less than ±5 cm, usage of Total Station and/or digital level with appropriate methodology with respect to the structure is mandatory;

(c) except the initial stage of rails installation, all the next stages till the final positioning, shall be stake out by using TGMT with GNSS/INS or TGMT with Total Station, to achieve the requested millimetre precision;

(d) equipment and accessories must be properly maintained, regularly checked, and calibrated for accuracy at the beginning of any survey project to ensure that the equipment is operating properly;

(e) Control Points checks shall be performed prior to any construction staking to ensure the benchmarks have not been disturbed and are within their original RB RAIL Minimum Construction Horizontal and Vertical Accuracy Tolerance for the item being staked.

9 As-Built survey

9.1 General instructions to the Contractor

130. The As-Built survey works needs to be carried out by Contractor during the construction of the Rail Baltica Project and this task shall include the following:

(a) the Contractor is responsible for verifying the adequacy and accuracy of any information that is forwarded/provided to him relating to the Project;

(b) prior to any of geodetic measurement for construction purpose (except the ground preparation works, like deforestation, topsoil removal, backfills and lower base layers where construction or installation tolerance is more than ±5 cm and works carried out by RTK-GNSS) the Contractor has to submit a Network Design and Measurement Report of geodetic network works to the Service for approval. IB-s may, due to the specification of the work, still require the immediate submission of the Network Design and Measurement Report before starting any geodetic works on construction site;

(c) the Contractor shall establish a geodetic network (CP1, CP2 and MNCP) on the site in accordance with the current geodetic work manual RBDG-MAN-039. As-built measurements and as-built models (for BIM purposes) and drawings must be based on the established geodetic network;

(d) carry out the as-built measurements of all works and prepare the corresponding as-built BIM models and drawings. The as-built measurements (BIM models and drawings) are finally handed over on a digital data carrier together with the execution documentation. The performance of the as-built measurements and the as-built models and drawings must comply with the following documents: RBDG-MAN-039, RBDG-MAN-040, with additional requirements of IB-s and with Country local based regulations;

(e) the digitally signed container of as-built documentation must contain as-built measurement RAW data, BIM models and drawings in native and open formats and 3D surface models in LandXML format;

(f) carry out as-built measurements of all utility networks to be rebuilt in accordance with the following documents: RBDG-MAN-039, RBDG-MAN-040, with additional requirements of IB-s and with Country local based regulations and/or in accordance with the requirements of utility network owners;

(g) the volumes of work completed must be indicated in the as-built drawing;

(h) the final as-built drawing must show the height numbers of the axis and edges of the top layer of the pavement, dug ditches, inflows and outflows of constructed culverts, facilities and curbstones (designed value, actual value, and their difference), the extent of landscaping, traffic management tools (vertical and horizontal ones), buildings, facilities, all utility networks (including communication, electricity, gas, water, sewerage, drainage, and heating), and lighting masts locations. The numbers must be distinguishable and clearly legible;

(i) it is allowed to carry out the as-built measurements of earthworks, except for the subballast layer, with terrestrial Laser Scanner and/or with UAV[2], using LiDAR[3] or Photogrammetry[4] methodology, if the Contractor has drawn up a corresponding programme of surveying work, which describes the surveying methodology, the establishment and use of reference points, which structural layers are to be measured, and it must be approved by the Service before the work is carried out. It is also necessary to perform and submit geodetic control measurements with sufficient frequency, using a more precise methodology, which confirm the accuracy of the drone surveying;

(j) all drone flights must comply with applicable laws, regulations and legislation in the country. The drone flights may only be performed by a person with the relevant remote pilot qualification. All necessary flight permits and approvals must be obtained to conduct the flights. All the mentioned documents must also be submitted to the Service;

(k) geodetic measurements (coordination) of the drone survey reference points must be performed with a Total Station and must be based on the RB geodetic network. If RB geodetic network is not available, the alternative solution based on national geodetic network have to approved with Service;

(l) “As Built” measurement of structures upon completion of the permanent lining , as well as “As Built” measurement of the Public Utility Objects network diversions and the reinstatement of all areas occupied for the Project needs;

(m) “As Built” measurement of the rails after the completion of the trackwork;

(n) to perform the geodetic (network) works on site, the contractor must use a surveyor with the appropriate competence and submit documents proving the competence.

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[2] **UAV** - Unmanned aerial vehicle. Commonly known as a drone, is an aircraft without any human pilot, crew, or passengers on board.

[3] **LiDAR** - Light detection and ranging. Method for determining ranges by targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver.

[4] **Photogrammetry** - Technology of obtaining 3D information about physical objects and the environment through the process of interpreting photographic images.

9.2 Geometrical controls and "As-Built" Survey of the Works

131. The Contractor shall conduct with the required accuracy both the geometrical controls upon the completion of each individual section of the structures executed throughout all Project construction phases (consolidation, cutting, filling, subbase, base, ballast, temporary and permanent lining) for stations, tunnels, structures, the remaining buildings, as well as the "as built" survey (using surveying methods) of all Rail Baltica works upon completion of each section of the alignment. Measurements shall be executed using equipment and methodologies described in Network Design and approved by Service.

132. During the excavation phase of stations, tunnels, bridge foundations and the remaining structures, the geometrical control of the works shall be carried out approximately every 5 meters and, during the temporary and permanent lining phase, the afore-mentioned geometrical control shall be conducted approx. every 10 meters. The geometrical control shall be submitted to the Service, in a way to be agreed upon, upon the completion of each individual section of the structure.

133. After the completion of the construction of the permanent lining of tunnels, stations, bridges and other structures or any part thereof, the Contractor shall proceed to the accurate measurement (as built survey) of the envelope approx. every 10m. In addition, after completing the construction of the buildings and the remaining structures, the Contractor shall accurately measure these buildings and their bearing elements (columns, walls, slabs, vertical axes, etc).

134. All the above works (geometrical controls and "as built" survey works) shall include the survey of the "as-built" envelope of the stations and tunnels, as well as the calculation of the horizontal and vertical offsets from the theoretical position. Based on these results, the Contractor shall submit documents presenting every measured as-built cross section as compared to its theoretical position, indicating the offset between the measured points and the theoretical alignment. The coordinates of each measured point shall be presented for every cross section, correlated both on the BIM 3D models, drawings and the documents. The Contractor will present in a drawing, complete with measurement results and the calculation method, the horizontal and vertical offsets from the as-built axis as compared to the theoretical one. Moreover, the Contractor shall provide the drawings reference numbers which are used for the theoretical base map (e.g. Layout Plan and Longitudinal Profile).

135. The data shall be submitted to the Service progressively depending on the completion of each of the above phases or part thereof.

136. The above data shall be presented in the form (to be agreed with the Service) of BIM 3D models, appropriate drawings, technical reports, containing all details related to the dimensions, the materials, etc., in a digital form.

137. The “as built ” survey after the completion of the respective portions of the Rail Baltica projects shall include adjacent buildings, structures and installations, so as to reflect the actual situation.

138. The above “as-built” BIM 3D models and drawings shall satisfy the requirements of RBR DG and the competent Authorities and shall be submitted to these Authorities and to the Service in a digital form as well for information and/or approval.

139. For all the above survey works, RB Rail reference system shall be used as reference system and the measurements shall be executed in co-relation to the ground level CP1, CP2 and MNCP geodetic and height networks.

140. In addition to conventional geodetic methodologies, as-built surveys can be done by laser scanning and/or photogrammetry devices that provide required precision. Requirements for laser scanning and photogrammetry are described in Annex 2, Laser Scanning and Photogrammetry requirements.

9.3 Geodetic and Height Network for Trackwork

141. The specifications mentioned in paragraph 7.6 of this article apply for the establishment of the CP3 geodetic and height network, which is based on the CP1 and CP2 geodetic and height network and shall be used in the construction of the trackwork. In addition, all geodetic measurements, the calculations, and the results shall be submitted to the Service for approval in due time and in digital form.

9.4 Trackwork alignment and geometrical control

142. The specifications and obligations mentioned in paragraph 7.6 of this article apply for trackwork alignment and control.

143. In order to geometrically check the trackwork alignment in all construction phases, the data pertaining to the concreting of the lines (lining and levelling) shall be submitted to the Service.

144. Control measurements for track quality shall be done according to EN-13848[5]. The values for accuracy and measurement uncertainty depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848, Part 1-6.

[5] EN 13848 - Standard: Railway applications - Track geometry quality:

— Part 1: Characterization of track geometry

145. Following paragraphs define additional requirements for works required by EN 13231[6].

9.4.1 Relative Track geometry

157. Acceptance measurements shall be carried out within a period not exceeding 6 weeks or after passage of maximum 1 500 000 tonnes after the completion of the works.

158. Relative track geometry shall be measured by a track recording vehicle or by a track construction and maintenance machine fitted with measuring equipment, both shall be in accordance with series EN 13848.

159. Relative track geometry longitudinal level and alignment shall be measured for both rails using D1 and D2 wavelength measurement methods. All measurements shall be sampled at constant distance-based intervals not larger than 0.5 m.

160. Standard deviation shall be calculated for every rail separately with a section length of 200 m. Measured sections shall overlap with each other.

161. For track geometry quality number of isolated defects per 1.0 km shall be counted according to EN 13848 – 5 for following geometrical parameters.

162. All measured tolerances shall be in compliance with EN 13231-1, speed range 230 km/h< V ≤360km/h .

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9.4.2 Absolute track position

163. Distances between tracks shall comply with tolerances for lateral position of the track. Accepted track shall comply with EN 13231-1.

— Part 2: Measuring systems - Track recording vehicles

— Part 3: Measuring systems - Track construction and maintenance machines

— Part 4: Measuring systems - Manual and lightweight devices

— Part 5: Geometric quality levels - Plain line

— Part 6: Characterisation of track geometry quality

[6] EN 13231 - Standard: Railway applications - Track - Acceptance of works:

— Part 1: Works on ballasted track - Plain line, switches and crossings

— Part 2: Acceptance of reprofiling rails in plain line, switches, crossings and expansion devices

— Part 3: Acceptance of reprofiling rails in track

— Part 4: Acceptance of reprofiling rails in switches and crossings

— Part 5: Procedures for rail reprofiling in plain line, switches, crossings and expansion devices

164. Geodetic measurements for verification of the absolute track positions shall be done using geodetic reference system built by Contractor.

9.4.3 Other parameters and verifications

165. SSP shall measure squareness of the sleepers. Permissible deviations from squareness of the sleepers is described in EN 13231-1.

166. Accepted ballast cross section shall comply with the tolerances in EN 13231-1.

9.5 As-Built Survey of the Trackwork

167. After the completion of the trackwork construction, submittal shall be made to the Service of the As-Built BIM 3D models and drawings, measurement data (coordinates, elevations, gradients), as well as any deviations from the theoretical line.

168. In order to preserve the characteristic points of the alignment even after the completion of the construction works, their coordinates shall be submitted to the Service and the respective horizontal and vertical data shall be placed on the catenary masts in a plasticized form.

9.6 Construction Tolerances

169. The methods adopted by the Contractor for checking the alignment - implementation of the Works and tolerances shall be subject to the Service's approval. No tolerances beyond those specified in the Contract documents or/and construction drawings shall be permitted.

170. During the construction, the Contractor may be required to remove and replace in a correct manner any section of the Project including, but not limited to, concrete linings, piles and structural reinforced concrete works which have been constructed outside the specified tolerances. In this case, the Contractor shall propose eventual remedial measures for the Service's review. It is at the Service's exclusive discretion to decide whether these measures are acceptable or whether full reconstruction in accordance with the specification is required. In case the Service accepts works of a lower quality or smaller dimensions as compared to the specified ones, then it must be done in accordance with the contract.

171. Before delivery of the works Contractor shall perform all necessary measurements for railway track to define compliance for minimum tolerances according to EN 13231. Control measurements for track quality shall be done according to EN 13848. The values for accuracy and measurement uncertainty depend on the type of measuring system and are given in the corresponding parts of the standard EN 13848-2, EN 13848-3 and EN 13848-4.

9.7 Updating and supplementing of the topographical drawings

172. The Contractor is obliged to convert all topographical drawings provided to him and which are in different reference systems, into drawings using the RB Rail Datum as a reference system if it is available.

173. The Contractor is obliged and responsible to constantly update the survey drawings with data obtained from the surface and underground level networks and structures, as these structures keep changing until the completion of the works, as well as after their completion, and compile new drawings, wherever required. All measurements and drawings shall use the RB Rail system as a reference system and all measurement works shall be correlated with the primary and the secondary geodetic and height networks of the project.

10 Construction of geodetic benchmarks

Related reference to follow: DG document No. RBDG-MAN-038 "GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTIONSTAGE OF RAIL BALTICA HIGH SPEED RAILWAY", 7.4 Construction of new geodetic benchmarks.

11 Documentation

Related reference to follow: DG document No. RBDG-MAN-038 "GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTION STAGES OF RAIL BALTICA HIGH SPEED RAILWAY", 7.5 Documentation.

12 Construction supervision by SSP

174. This chapter defines additional scope of work for construction SSP and additional requirements for "Common minimum requirements regarding construction supervision

rules" document regarding railway construction and geodetic network construction supervision services.

175. Main responsibilities:

(a) confirming the quality of new geodetic and height network for constructing highspeed railway according to requirements in this document and applicable standards and legislations;

(b) confirming that constructed volumes, layers widths and thicknesses are carried out in accordance with the project on the basis of BIM model and BOQ;

(c) confirming that track geometry complies with minimum tolerances according to applicable standards and legislations;

(d) continuous reporting of possible deviations during construction.

176. SSP shall:

(a) timely obtain information on the possible deviation of the construction from project conditions and data;

(b) find out the deviations between the project and as-build data and report to Client if necessary.

177. To ensure the quality, preciseness, and correctness of as-built high speed railway compliance to Detailed Technical Design, Technical Specifications, BoQ and applicable European Standards, an external Supervision services shall be provided.

178. Main tasks (not limited to) for SSP during Railway construction:

(a) to ensure construction compliance for DTD and BoQ;

(b) participate and ensure compliance with DTD and BoQ in the marking works of structural layers, track and systems;

(c) conduct control measurements of railway embankment, cuttings, prepared subgrades, sub-ballast and ballast geometrical parameters (widths, thickness, volume) in order to define structural layers geometry compliance to DTD, BIM models and BoQ. Control measurements in order to define as-built drawings compliance for DTD and BoQ shall be done after 60 m at least;

(d) evaluate and approve as-built models;

(e) propose changes in BIM models according to approved as-built data, if necessary;

(f) construction SSP shall compare as-built data (volumes, geometry) with BIM models of DTD Design after each stage of construction works, in case of non-conformities deviations shall be reported to Client and Contractor immediately;

(g) visually record (for example, in a photograph) the completion of the construction work stages specified in the construction supervision plan;

(h) organize both work and admission committee meetings if necessary;

(i) prepare deductions and financial calculations from the cost of the Work performed if there are changes in the volumes in the Contract or the Contractor has performed the work to a poor standard;

(j) organize and formalize intermediate and final inspections of mentioned superstructure construction Works, approve the Contractor's application for acceptance of the Work when the Work has been completed in accordance with the Contract and submit to the Client a confirmation of completion of the Work and submit a final report within one month of issuance;

(k) create a report after completion of works for certain structural layer.

179. SSP shall use measurement devices with similar or higher precision required from the Contractor.

12.1 Construction supervision plan

180. Construction SSP shall develop respective Construction supervision plan or quality control plan which must be submitted and approved by Client and respective authorities required by state law. Construction supervision plan or quality control plan regarding construction of Geodetic and height network and construction of high-speed railway supervision services shall consist in minimum of:

(a) construction and material quality control procedures, including descriptions of the works to be inspected, inspection frequencies, possible tests or measurements;

(b) procedures for notification of construction deficiencies and their elimination;

(c) procedures of fulfilling main tasks of SSP;

(d) SSP shall provide to Client for acceptance all details about the involved Geodesy Crews.

12.2 Construction supervision of the geodetic network

181. During the construction of the geodetic and height network, the following are the primary responsibilities of supervision service providers:

(a) to be involved in construction process implementation and to check constructed control point by recording implementation data online in RB Rail AS GIS map platform and filling in required data;

(b) to constantly inform the Client about the quality and progress of the Works;

(c) check and demand compliance with Network Design and Work execution plan during geodetic network construction;

(d) check documentation of control points;

(e) check whether prepared data is integrated into RBR GIS platform;

(f) document and submit deviations from the requirements provided in Contract and applicable legislations. Deviations shall be reported to Client immediately;

(g) to check whether all control points are constructed according to current TS, state law and Network Design;

(h) conduct regular control measurements for Control points according to procedure described in Construction Supervision plan submitted to and approved by Client;

(i) inspect and verify measurement deviations for control points (CP0, CP1, CP2, CP3, MNCP);

(j) review, and approve calculation parameters for implementing unified RBDatum across all Baltic states;

(k) review, and approve cross border established height system (systems) with existing height data in the neighbour country;

(l) make entries in the construction work log, including deficiencies found during site inspections and the absence of the responsible construction work manager in time of performed construction works;

(m) visually record (for example, in a photograph) the completion of the construction work stages specified in the construction supervision plan;

(n) inspecting the management of measurement data collected in the field and data in BIM models (designed information);

(o) evaluate, check and, if compliance, approve the construction drawings, reports, certificates, documents certifying the conformity of materials and products, test reports of materials and works submitted by the Contractor and submit them to the Contracting Authority within 5 working days of their submission by the Contractor;

(p) verifying the final documentation produced by construction company whether implemented geodetic network is in accordance with accuracy requirements in this document and applicable standards and legislations in specific country where CP are built in.

182. SSP shall prepare reports of:

(a) review of existing geodetic networks before beginning of construction works;

(b) review, measurement verification and calculation reports produced by Contractor;

(c) final report presenting the detailed assessment and presenting non-conformities including recommendations for improvement;

(d) provides systematic and random errors of geodetic networks CP0, CP1, CP2 and MNCP.

13 Additional supervision

183. Depending on available resources, Client (RB Rail and/or IB) shall supervise all works mentioned in this document starting from building new geodetic points for geodetic network till acceptance of railway track.

184. To ensure the quality of Geodetic Reference System, Height system and control network an RBR and IB-s shall inspect the chosen Reference System, Height System and the control network.

185. In accordance to high speed railway construction accuracy requirements and scope of work defined in respective local law, the RBR and IB-s shall perform all necessary tasks to ensure that the quality of Geodetic Networks is in accordance to all applicable laws and standards for constructing highspeed railway.

186. The main tasks (not limited to) that Client shall perform before construction works:

   (a) get design solutions defined by the requirements solutions for establishing of geodetic network;
   (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 Contractor 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 Contractor’s proposals and give notification to Client;
   (d) review, approve and provide opinion for Contractor Network Design before beginning of construction works;
   (e) verify imposed standards and regulations;
   (f) check and coordinate the compliance of the Contractor's subcontractors with the Contract terms;
   (g) check and verify calibration certificates of instruments used for geodetic measurements, inform the Service provider about the use of non-compliant equipment;
   (h) to review and approve Contractor method of railway track construction using CP2 geodetic network points to assure railway track construction tolerances according to EN 13231.

187. Main tasks for Client supervision:

   (a) regular site visits to ensure SSP and Contractor work quality;
   (b) approve SSP reports;
   (c) random checks for As-built data vs. design;

(d) random laser scanning and/or photogrammetry to follow construction work progress. Additional Supervision process using laser scanning/photogrammetry methods is described in Chapter 13.1 "3D inspection – laser scanning and UAV";

(e) Review of UAV (drone) photos and/or videos after every major construction phase. UAV video recording is described in DRCHS.

13.1 3D inspection – laser scanning and UAV

188. The additional supervision works may consist of additional control measurements using different methods, including, but not limited to laser scanning/photogrammetry as well as all conventional methods.

189. UAV must be used also to record a fly over video to capture the construction work progress of the whole Construction object. The angle and view of the video shall clearly show the conducted construction works and progress of them. If one angle and view of the video cannot show the entire work progress, then additional video recordings are shall be performed to capture the entire Construction object and all areas. The UAV shall circulate around (360 degrees) a point type objects (e.g. bridges, overpasses, viaducts, etc.) to capture the obscured or hidden areas.

190. The video files shall be stored on the Client's CDE.

191. Technical specification of the video as minimum shall be:

(a) resolution: 1920x1080px;

(b) file format: *.MP4 or *.MOV (encoded using H.264 codec for the best quality/file size ratio);

(c) at least 25 fps.

192. If there are places where UAVs cannot be used (e.g. inside tunnels, under smaller bridges, restricted fly zones, etc.) the video recording shall be done using alternative methods. In case the weather conditions are prohibiting to do the UAV flights for video recording/laser scanning/photogrammetry, other methods shall be used in order to comply with the schedules of capturing the above-mentioned information.

193. During the inception/mobilization stage, the Client must inform the General Contractor about the planned activities. If in some areas, the flights are limited or not possible, the General Contractor shall inform the Client and propose an alternative method on how to collect the data.

14 Geodetic and height network for maintenance

194. An essential ingredient for successful running of a High-Speed Railway is well-developed and advance maintenance system.

195. The track condition tends to deteriorate due to external factors, such as the frequent passage of heavy trains and deformation of the track bed. These factors make the railway track drift away from its designed geometric position and result in track irregularities so accurate measurement of the track geometry is a task of fundamental importance for adjusting deformed tracks and ensuing high operational safety.

196. The overall railway track geometry condition of the existing line is inspected regularly by dedicated track inspection trains or track recording vehicles owned by the railway management department. Dedicated track inspection trains can survey at high speed, but provide only relative information which hardly conforms to the accuracy requirements in the determination of the track geometric deformation and their related localization for tasks such as precise track adjustment applications.

197. Lightweight and flexible track geometry measuring trolleys (TGMTs) in combination with high precision and annually traceably calibrated geodetic measurement apparatus shall be used for geometry measurements of unloaded tracks, and provide follow-up accurate measurements after the dedicated track inspection train for regular maintenance of existing lines and accurate measurement for alignment, precise adjustment, or tamping applications during the railway construction stage. Measuring trolleys must be traceably calibrated annually.

198. The TGMT with GNSS/INS module can realize submillimetre relative accuracy in inner track geometric parameter measurement including the track deformation/displacement or track irregularity measurement, however this is not sufficiently accurate for determining the absolute position of the track when millimetre absolute positioning accuracy is required. Therefore, TGMT with total station shall be used to get submillimetre accuracy relative to track geodetic network. For that purpose, CP3 control points located on catenary masts shall be used by specific TGMT system.

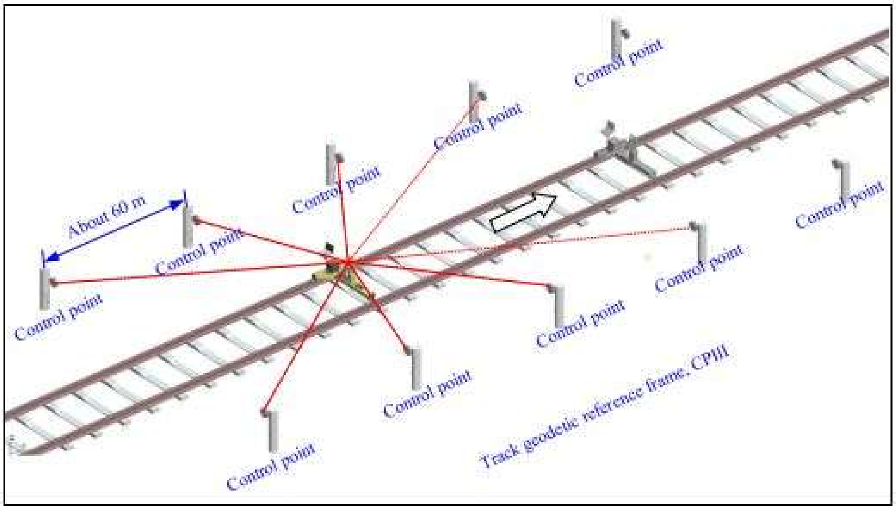


Figure 9. Maintenance with geodetic Trolley system

199. Possible deviations in operating phase will be identified using as-build data in BIM environment that is approved by Construction supervision service provider.

200. To define possible embankment settlement which also infects catenary masts a regular measurement shall be done for CP3 using CP2 and CP1 implemented by Contractor during geodetic network construction.

201. Rail Baltica project will be prepared using assets register system which will be integral system to GIS and BIM models. Infrastructure manager/r's will be responsible for Rail Baltica railways maintenance and operational works, and it is obligatory to use asset register system with updated RB Geodetic and Height network information.

15 References

15.1 Standards

ISO 17123 Optics and optical instruments. Field procedures for testing geodetic and surveying instruments:

— Part 1: Theory

— Part 2: Levels

— Part 3: Theodolites

— Part 4: Electro-optical distance meters (EDM measurements to reflectors)

— Part 5: Total stations

— Part 6: Rotating lasers

— Part 7: Optical plumbing instruments

— Part 8: GNSS field measurement systems in real-time kinematic (RTK)

— Part 9: Terrestrial laser scanners

EN 13848 - Standard: Railway applications - Track - Track geometry quality:

— Part 1: Characterization of track geometry

— Part 2: Measuring systems - Track recording vehicles

— Part 3: Measuring systems - Track construction and maintenance machines

— Part 4: Measuring systems - Manual and lightweight devices

— Part 5: Geometric quality levels - Plain line

— Part 6: Characterisation of track geometry quality

EN 13231 Railway applications - Track - Acceptance of works:

— Part 1: Works on ballasted track - Plain line, switches and crossings

— Part 2: Acceptance of reprofiling rails in plain line, switches, crossings and expansion devices

— Part 3: Acceptance of reprofiling rails in track

— Part 4: Acceptance of reprofiling rails in switches and crossings

— Part 5: Procedures for rail reprofiling in plain line, switches, crossings and expansion devices

15.2 Local norms

All local norms and guidelines that regulate geodetic works in Estonia, Latvia and Lithuania.

15.3 Applicable Guidelines

RBDG-MAN-038-0102 - Geodetic Network establishment for Design and Construction stages of rail Baltica high speed railway

RBDG-MAN-030-0107 - Building Information Management (BIM) Employer's Information Requirements

RBDG-MAN-033-0103 – BIMManual

RBDG-MAN-040-0102 – Digital Information Requirements for Construction and Handover Stages

RBGL-DMT-PRC-Z-00001 - Document Numbering and File Naming Procedure

RBGL-DMT-LST-Z-00001 - Document Numbering and Master Coding

RBDG-MAN-034-0102 - CADStandards

16 Annexes

Annex1. Detailed Technical Requirements for Geodetic and Height network

Annex2. Laser scanning and photogrammetry requirements

Annex3. Other requirements

ANNEX1 – DETAILED TECHNICAL REQUIREMENTS FOR GEODETIC AND HEIGHT NETWORK

Related reference to follow: DG document No. RBDG-MAN-038 “GEODETIC NETWORK ESTABLISHMENT FOR DESIGN AND CONSTRUCTION STAGES OF RAIL BALTICA HIGH SPEED RAILWAY”, 9. ANNEXES / Annex 1. Detailed Technical Requirements and Annex 2. Benchmarks construction

ANNEX2 - LASER SCANNING AND PHOTOGRAMMETRY REQUIREMENTS

1 General information of application of additional measurement methods

Table 7. Methodology tolerances and precision

Item	Additional measurement method	
	Laser scanning (TLS, MLS, LiDAR) and Photogrammetry	Photogrammetry
Purpose	As-Built information and progress monitoring	Progress monitoring
Methodology tolerances and precision	Where the required accuracy for point cloud is **<25 mm** and required tolerance for **GSD**[7] **≤ 25 mm**	Where the accepted tolerance for point cloud is **>25 mm** and accepted tolerance for **GSD > 25 mm**
Coordinate/height system	EE_L-EST97/EH2000, LV_LKS-92 TM/LAS-2000,5, LT_LKS94 TM/LAS07 or RBDatum, if exist	EE_L-EST97/EH2000, LV_LKS-92 TM/LAS-2000,5, LT_LKS94 TM/LAS07 or RBDatum, if exist
Requirements for Technical Specifications of equipment	TLS, MLS, LiDAR: 3D point accuracy ±3mm at 50m Photogrammetry: 1. Lens with a fixed focal length	N/A

[7] ***GSD*** *– Ground sampling distance (GSD) is the distance between the center of two consecutive pixels measured on the ground. GSD of 3 centimetres means one pixel in the image represents 3 linear centimeters on the ground. The same pixel will cover 9 square centimetres (3 x 3 centimetres). Generally, in a flight project which has been correctly reconstructed, then expected relative accuracy to be within one to three times the ground sampling distance (GSD). The absolute accuracy of a correctly reconstructed project is one to two GSD horizontally (X and Y) and one to three GSD vertically (Z).design*

	2. Mechanical or electronic shutter. (not rolling shutter) 3. RTK or PPK antenna	
Application type	1. All earthworks: a. All layers of embankment (sub-structure) b. Cuts and all layers before superstructure 2. All point-type objects: a. Stations, stops, halts, platforms, etc. b. Infrastructure Maintenance Facilities, Depots, etc. c. Bridges, viaducts, overpasses, underpasses, etc. d. Ecoducts e. Large and medium sized culverts (all concrete culverts) f. Retaining walls and noise walls g. Underground utilities (before covering) h. Railway systems, electrification and signalling equipment (catenary posts, energy sub-stations, etc.) i. Railway superstructure NOTE: Any other point-type infrastructure object which is not listed shall be agreed with the Client and RB Rail	Overall progress monitoring of construction site in every stage
Type of deliverable	a. RGB Point cloud (simplified and cleaned from unnecessary points) b. 3D surface mesh - DTM c. Orthomosaic raster images (photogrammetry only)	
Classification	Delivered point clouds shall be classified in the following categories, but not limited to: a. Ground b. Low vegetation c. Medium vegetation d. High vegetation e. Buildings f. Structures (Bridges, viaducts, overpasses, underpasses, etc.) g. Water h. Rails i. Road surfaces	N/A

	j. Transmission towers and other railway systems, electrification and signalling equipment k. Unclassified **NOTE:** Exact classification shall be agreed in the BEP or in other equivalent document, accepted by IB-s.	
File formats	3D surface mesh: OBJ/TIF/ECW Point cloud: Terrestrial scans: E57 and RCP/RCS UAV scans: LAS/LAZ/E57 Orthomosaic raster images TIF/ECW	3D surface mesh: OBJ/TIF/ECW Point cloud: LAS/LAZ/E57 Orthomosaic raster images TIF/ECW
Data collection method	Terrestrial, mobile and UAV (Aerial)	UAV (Aerial)
Data collection frequency	At least monthly or according to agreement, if specified	

202. The exact equipment and methodology shall be agreed in the full BEP or in other equivalent document, accepted by IB-s.

2 File formats

203. The results of the point clouds shall be submitted in National coordinate/height system (or in RB system, if available) in two formats – Navisworks-ready ReCap-processed point cloud (RCP and RCS) together with one of the following master formats of LiDAR technology:
    (a) 3D Pointcloud Terrestrial scanning - E57 and RCP/RCS, both with station data;
    (b) 3D Pointcloud UAV scanning – E57/LAS/LAZ;
    (c) Orthomosaic – GeoTIFF/JPG/ECW (other formats may apply but shall be agreed separately in BEP or in other equivalent document, accepted by IB-s.);
    (d) 3D Surface model – OBJ/3DS/STL/LandXML.

204. The exact file formats shall be agreed in the full BEP or in other equivalent document, accepted by IB-s.

3 Scanning tolerances and precision

205. The tolerances for measurements (x,y,z) with laser scanning/photogrammetry for construction as-built information shall be the following:

(a) civil structures (bridges, overpasses, viaducts, tunnels, culverts, etc.), concrete and steel structures and it's elements: +/- 8 mm;

(b) maintenance and access roads, its elements and equipment: +/- 20 mm;

(c) earthworks, cut surfaces, layers of compacted embankment structure: +/- 25 mm;

(d) station buildings, its elements and systems, platforms, stops and its elements: +/- 8 mm;

(e) railway systems, electrification and signalling equipment: +/- 20 mm;

(f) other elements: agreed separately with Client.

206. NOTE: Measurement result together (including discrepancies, if using National coordinate/height systems) with allowable tolerance mentioned above must fulfil the applicable construction tolerance stipulated in Country's legislation, laws, standards and regulations.

207. None of the above-mentioned procedures and tolerances does not exempt the General Contractor not to perform all the legal procedures stipulated in the Country's legislation, laws, standards and regulations. If the requirements in this document contradicts with the requirements stipulated in the Country's legislation, laws, standards and regulations it shall be agreed separately in BEP or in other equivalent document, accepted by IB-s.

4 Guidance of laser scan/photogrammetry stages

4.1 Bridges, viaducts, overpasses, underpasses and other point-type infrastructure objects

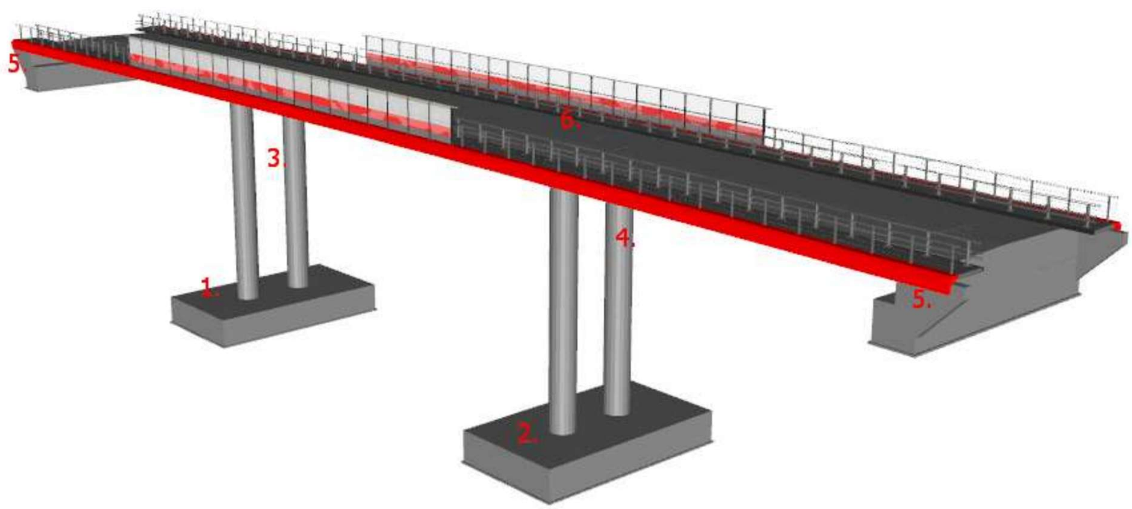


Figure 10. Bridge or viaduct elements required for scanning

1. Scanning of pile cap 1 after formwork removal
2. Scanning of pile cap 2 after formwork removal
3. Scanning of overpass pier / pier set 1
4. Scanning of overpass pier / pier set 2
5. Scanning of both abutments
6. Scanning of finished deck, top and bottom

7. Overall complete scan of the structure including all the secondary elements, e.g. crash barriers, catenary posts, railing, etc. (as-built situation). Elements that are hidden but previously scanned can be included in the final point cloud.

4.2 Ecoducts

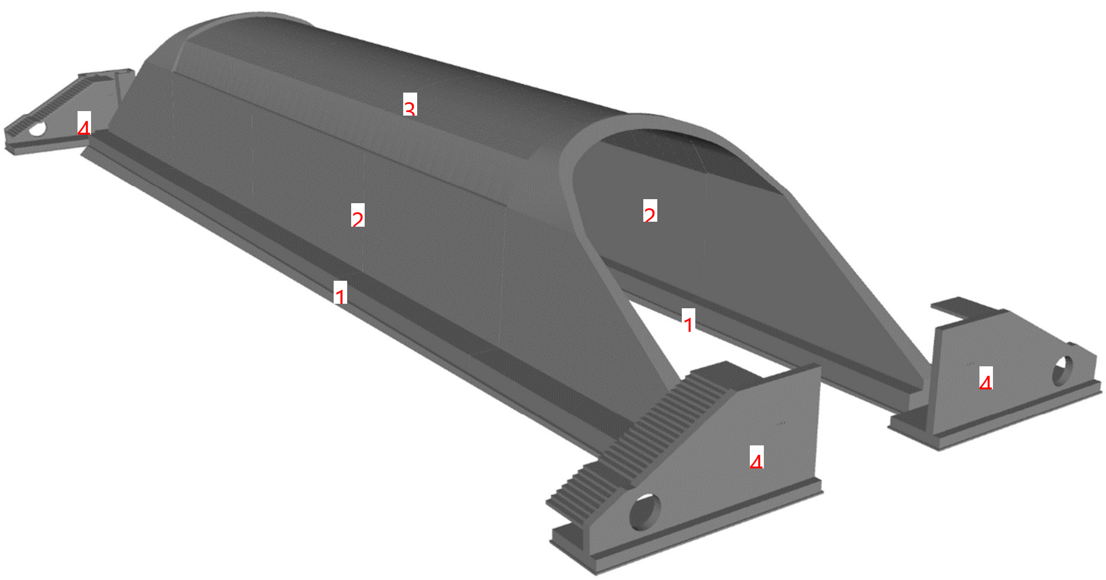
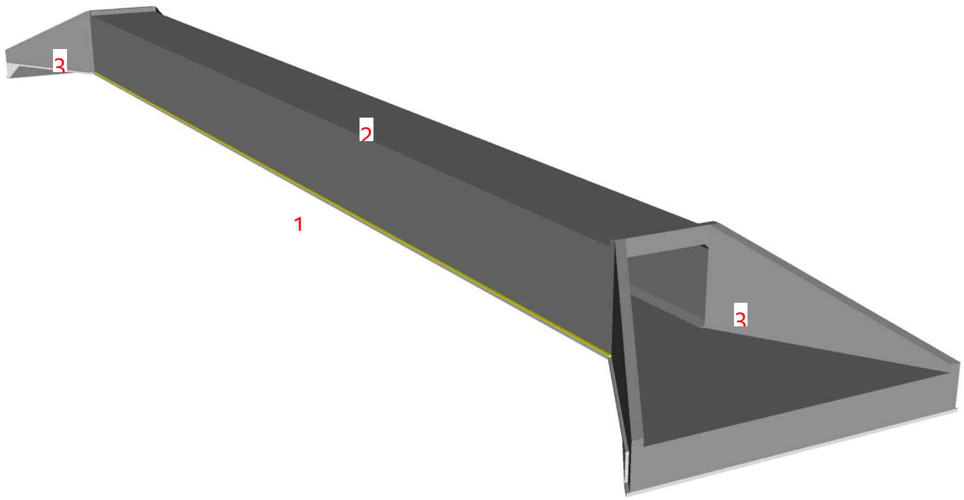


Figure 11. Ecoduct or tunnel elements required for scanning

1. Scanning of concrete foundation after formwork removal
2. Scanning concrete walls after formwork removal
3. Scanning precast vault
4. Scanning of wingwalls, stairs and other auxiliary elements after formwork removal
5. Overall complete scan of the structure including all the secondary elements before the backfilling and natural soil cover. Elements that are hidden but previously scanned can be included in the final point cloud.

4.3 Large and medium sized culverts (all concrete culverts)



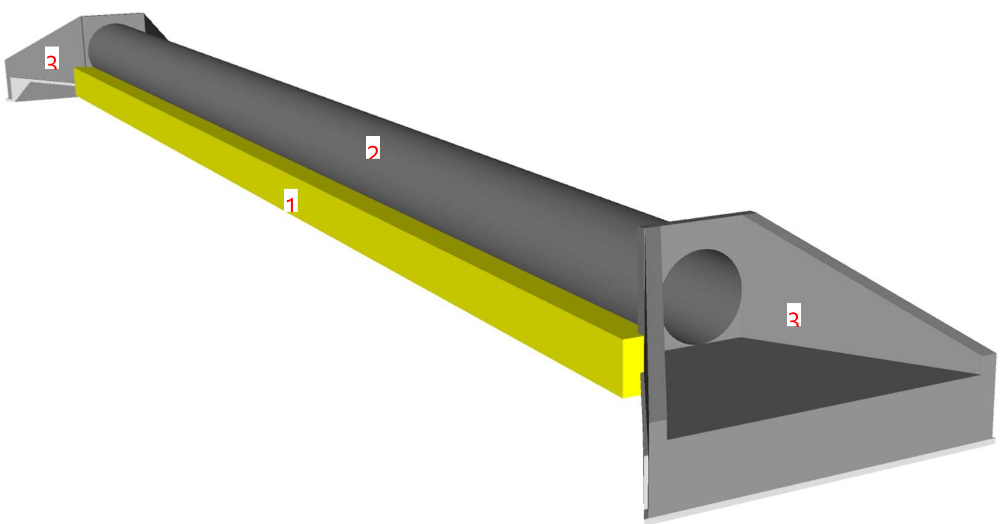


Figure 12. Culvert elements required for scanning

1. Scanning of the levelling concrete foundation
2. Scanning to the main culvert after concreting/installing it
3. Scanning of the wingwalls after the formwork removal

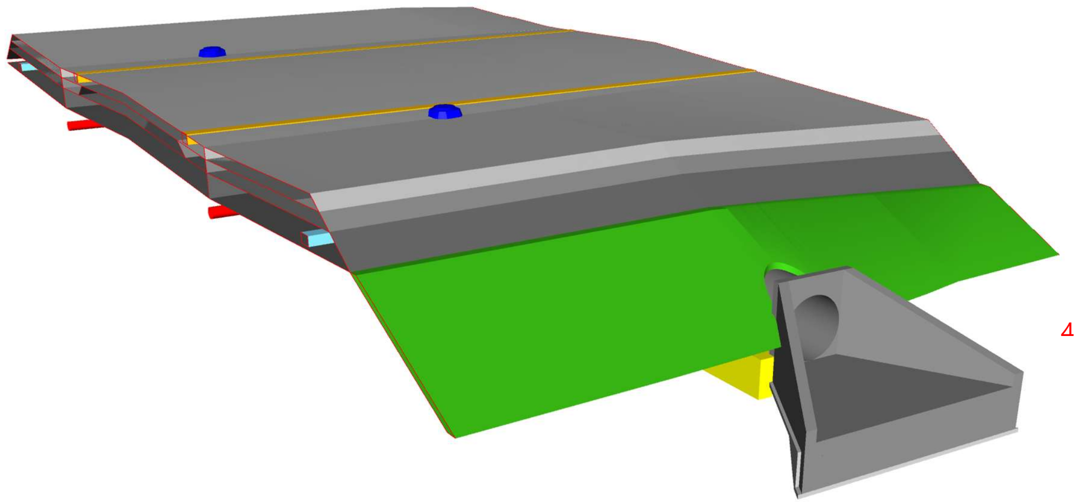
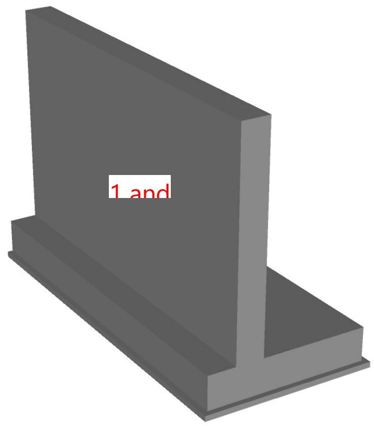


Figure 13. Elements to be scanned after backfilling

4. Overall complete scan of the structure after the backfilling and compacting the embankment structure. Elements that are hidden but previously scanned can be included in the final point cloud.

4.4 Retaining walls and noise walls



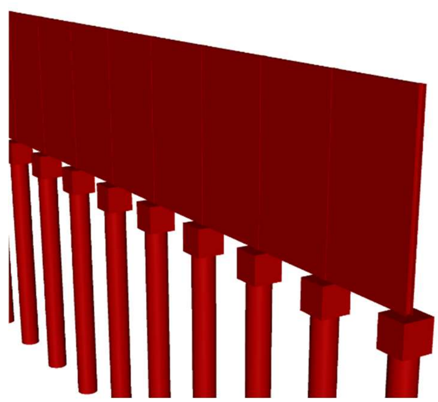


Figure 14 and 15. Wall elements required for scanning

1. Overall complete scan of the structure before backfilling it
2. Overall complete scan of the structure after backfilling it. Elements that are hidden but previously scanned can be included in the final point cloud.

4.5 Underground utilities

206. The laser scanning of top of underground utilities shall be performed before covering.

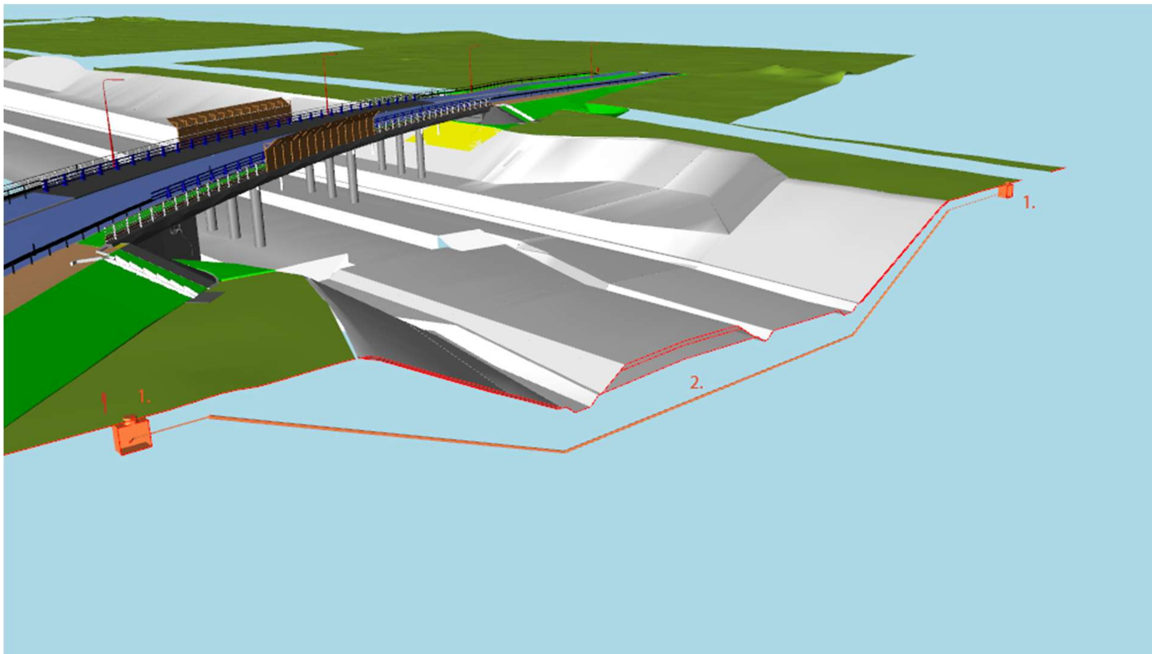


Figure 16. Required underground utilities to scan

1. Scanning detailly of major utility connections and ends;
2. Scanning of top of utility min every 20 m, or at a sufficient distance for the communications to be detectable from the point cloud. The number of stations depends on the technical specifications of the scanner used.

4.6 Linear objects (embankments, cuts, etc.)

209. The photogrammetry or terrestrial(mobile) laser scanning of linear objects shall be performed partially or continuously for all the layers and surfaces on the entire width (*ca* 31 m) of the right of way for the railway line. Partially measured layers and surfaces must be cleaned and joined into a single point cloud.

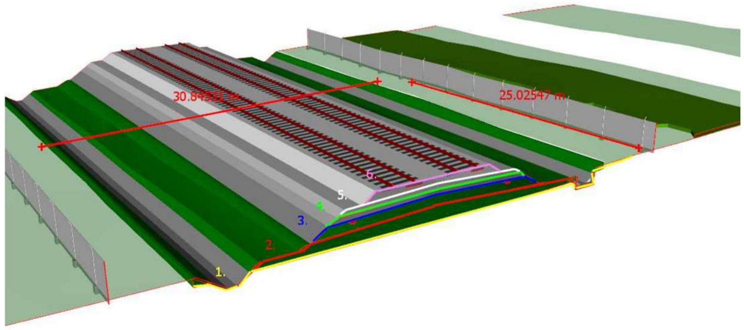


Figure 17. Example of required area to scan

1. Scanning of surface after excavation
2. Scanning after laying and compaction of fill layer
3. Scanning after laying and compaction of frost-resistant layer
4. Scanning after laying and compaction of subgrade fill layer
5. Scanning after laying and compaction of sub-ballast layer
6. Scanning after laying and compaction of ballast track bed

4.7 Other requirements

210. Exact laser scanning program and sequencing for construction objects shall be agreed in BEP document or in other equivalent document, accepted by IB-s, including, but not limited to:
    (a) PK measurement;
    (b) site ID/VolSystem ID of the structure;
    (c) types/sequences of laser scans to be performed;
    (d) equipment used for the scans;
    (e) achievable tolerances of the scans
    (f) file formats to be delivered.

211. Laser scanning and/or photogrammetry schedule shall follow the progress of the construction works.

212. Detailed schedule and exact scan location, phasing and frequency listing all the construction works after which the scanning and/or photogrammetry will be carried out shall be agreed in BEP or in other equivalent document, accepted by IB-s.

ANNEX 3 - OTHER REQUIREMENTS

1 UAV use cases during the construction stage

212. Usage of Unmanned Aerial Vehicles (UAV – commonly known as drones), shall be used on construction sites for gathering data by LiDAR and/or photogrammetry methods. Other use cases and data collection methods using UAVs may apply.

213. All UAV flights must comply with the respective Countries laws, regulations and legislation.

214. All safety measures and procedures must be established to ensure safe usage of UAVs.

215. It is the direct responsibility of the General Contractor to ensure that all UAV flights are performed by a licensed pilot (if Country's legislation requires it) and that all the required authorizations and permits are received in order to perform the flights within the respective construction object.

216. The UAV flights shall be planned in good weather conditions in order to achieve the quality of the scanned data and to ensure safety. Flights cannot be performed in dark or during night-time or during bad weather conditions – during snowfall, rainfall or fog. During the wintertime, the flights can be performed with a condition, that snow cover does not affect the accuracy of the measurements – the snow must be cleaned before scanning the area (only for smaller areas where feasible). After heavy rain or in areas with high groundwater levels, the scanning of trenches and/or cuts must be performed, when there is no water (puddles) in the area of scanning within the construction site.

217. In some construction objects, the nearby infrastructure might prohibit or have limitations for such flights – e.g. nearby airports, nearby critical infrastructure objects, nearby military objects, etc. Other restrictions may apply.

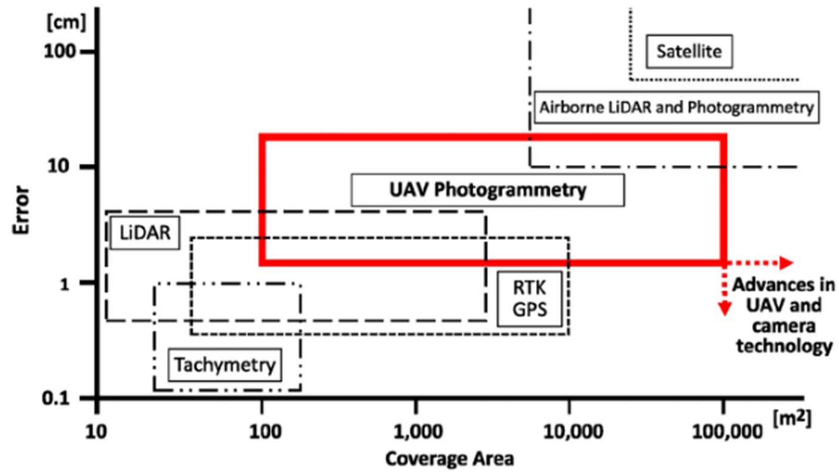


Figure 18. Usage area of UAV

2 Specifications for Ground Control for Photogrammetric Mapping

2.1 General

218. This document covers ground control requirements for photogrammetric mapping projects. The fundamental requirements for control network configuration, point location, and characteristics are discussed in this document. However, the overview presented is not intended to be used for field survey design. Survey Engineer, in charge of photogrammetric mapping should refer to appropriate survey standards and specifications for guidance in designing the project control surveys. Current standards should be employed, and outdated standards and practices should be revised from time to time.

2.1.1 Geodetic and Height Reference System

219. In each country, all designing, and construction shall be carried out according to RBDatum if available (see RBDG-MAN-038, Chapter 3-5). If not available, National Systems can be used (see Table 8).

Table 8. Countries' Coordinate and Height systems

Country	Coordinates	Height
Estonia	L-EST97	EH2000
Latvia	LKS-92 TM	LAS-2000,5
Lithuania	LKS94 TM	LAS07

2.2 Ground Control Requirements

220. Field surveying for photogrammetric control is generally a two-step process. The first step consists of establishing a network of basic control in the project area. This basic control consists of horizontal control monuments and benchmarks of vertical control that will serve as a reference framework for subsequent surveys. The second step involves establishing photo control by means of surveys originating from the basic control network. Photo control points are the actual points appearing in the photos (photo identifiable points that are used to control photogrammetric operations. The accuracy of basic control surveys is generally of higher order than subsequent photo control surveys. The ratio of GCP reference and control points should remain 60/40. For example, on the linear object up to 4-5 GCP every 1 km should be established, where 3 points will remain for reference and 1-2 for control.

221. GCP coordination must be done only by Total Station from RB CP1, CP2 and/or from MNCP.

2.2.1 Basic Control

222. A basic control survey provides a fundamental framework of control for all project-related measurements, such as property measurements, photo control surveys, location and design surveys, and construction layout. The accuracy, location, and density of the basic control must be designed to satisfy all the project tasks that will be referenced to the control.

223. In planning the basic control survey, maximum advantage should be taken of existing control networks established in the area. Care should be exercised before using any existing control points to verify that they are adequately interconnected or are adequately connected to the national Geodetic network or in RB geodetic network (if available).

2.2.2 Photo Control

224. Photo control points are photo identifiable or panel points that can be measured on the photograph and stereomodel. Photo control points are connected to the basic control framework by short spur traverses, intersections, and short level loops. Lengthy side shots and open traverses should be avoided. The number of PCP depends on the size of the object, but could remain at 1 PCP for every 3 GCP-s.

225. Photo control surveys are local surveys of limited extent. Photo control points are surveyed to the accuracy required to control the photogrammetric solution.

2.2.2.1 Characteristics

226. Photo control points should be designed by considering the following characteristics: location of the control point on the photograph; positive identification of the image point; and measurement characteristics of the image point. 217. PCP coordination should be done only by Total Station from RB CP1, CP2 and/or from MNCP.

   (a) Location. Of the characteristics listed above, location is always the overriding factor. Photo control points must be in the proper geometric location to accurately reference the photogrammetric solution to the ground coordinate system. Photo control points should define a long line across the photographic coverage. The control points accurately fixes the scale and azimuth of the solution and fixes the elevation datum of the solution. The location should be established in accordance with current photogrammetric practice considering the project area and the map accuracy requirements.

   (b) Identification. The identification of the photo control points on the aerial photography is critical. Extreme care should be exercised to make this identification accurate. The surveyor should examine the photo control point in the field with the aerial photographs. Once a photo control point is identified, its position on the photograph should be recorded and a brief description and sketch and/or cutout of aerial photo, of each point should be made. Each photo control point should be given a unique name or number.

   (c) Measurement. Subject to the constraints imposed by location considerations, photo control points should be designed to provide accurate pointing characteristics during photogrammetric measurements.

2.2.3 Ground Control Distribution

227. If the project is small, requiring just a few models, the control can be established on the ground by conventional field or GNSS measurements (see Pt. 2.2, Ground Control Requirements). The absolute geometric minimum amount of photo control needed in each stereomodel is five (5) points.

228. For larger projects requiring aerial triangulation, the distribution of ground control is discussed in the chapter for Aerial Triangulation.

229. If RTK/PPK-GNSS UAV procedures are integrated into the photographic flight the amount of primary ground control points required may be further reduced. Its distribution is also discussed in the document for Aerial Triangulation.

2.3 Marking Photo Control

230. Photo identifiable control points can be established by marking points with targets before the flight or by selecting identifiable image points after the flight.

2.3.1 Premarking

231. The preferred method is premarking of photo control points. Marking control points with targets before the flight (if permanent targets are not available) is the most reliable and accurate way to establish photo control points. Survey points in the basic control network can also be targeted to make them photo identifiable. When the terrain is relatively featureless, targeting will always produce a well-defined image in the proper location. However, premarking is also a significant expense in the project because target materials must be purchased, and targets must be placed in the field and maintained until flying is completed. The target itself should be designed to produce the best possible photo control image point. The main elements in target design are good colour contrast, a symmetrical target that can be centered over the control point, and a target size that yields a satisfactory image on the resulting photographs.

   (a) Location. Target location should be designed according to the ground control distribution for aerial triangulation. However, it is difficult to ensure that the target will fall in the planned location in the photograph when the photography is flown. Care should be taken that targets are not located too near the edge of the strip coverage so that the target does not fall outside of the model.

   (b) Shape. Targets should be symmetrical in design to aid the operator in pointing on the control point. Typical shapes that may be used are "+", "T" or "Y" shape.

   (c) The area where the targets are located must be flat. Targets may not be placed on top of higher bumps or elements.

2.3.2 Postmarking

232. Alternative method is the postmarking method, which consists of examining the photography after it is flown and choosing natural image features that most closely meet the characteristics for photo control points. The selected features are then located in the field and measured from the basic control monuments. One advantage of postmarking photo control points is that the control point can be chosen in the optimum location (the corners of neat models and in the triple overlap area). The principal disadvantage of postmarking is that the natural feature is not as well defined as a targeted survey monument either in the field or on the image.

233. Typical feature that may be used for postmarking photo control points include:

   (a) traffic lines;

   (b) sidewalk intersection (must be perpendicular);

   (c) tennis Court, Basketball Court, Football field lines intersection.

2.3.3 RTK/PPK UAV

234. RTK/PPK UAV are now recommended for Drone mapping. This procedure involves establishing the horizontal and vertical location, and attitude of the principal point of every photo at the instant of exposure. If all conditions are ideal for RTK/PPK UAV (i.e., satellite configuration and signal, geoid model consistency), the minimum ground control would

be still required. In practice, measurement without ground control is not an acceptable risk considering the cost of deploying equipment and personnel to revisit the project site if problems surface after the flight. Therefore, minimal ground control should be planned. Flights plan may also incorporate a few cross flights to increase strength and accuracy to the block.

2.4 Deliverables

235. Unless otherwise modified by the contract specifications, the following materials will be delivered upon completion of the control surveys:

(a) General report describing the project and survey procedures used including description of the project area, location, and existing control found; description of the basic and photo control survey network geometry; description of the survey instruments and field methods used; description of the survey adjustment method and results such as closures and precision of adjusted positions; justification for any survey points omitted from the final adjusted network and any problems incurred and how they were resolved.

(b) Details of each control points, showing X, Y planar coordinates and Height and sketch or cutout photograph with control point clearly marked. Date and time, surveyor name, organization, as well as comments if any.

(c) A list of the adjusted (or arithmetic mean of RTK-GNSS points) coordinates of all ground control points.

(d) Extract from native software, with GCP adjustment results and errors.

3 Specifications for Aerial Triangulation

3.1 General

236. These specifications pertain to the aerial triangulation of standard, wide-angle aerial digital exposed with average of 60 percent forward overlap and 60 percent side overlap. The specifications apply to both strips and blocks of photography.

3.2 Aerial Triangulation

3.2.1 Definition

237. Aerial triangulation is the process of densifying and extending ground control through computational means. The process "bridges" or carries ground control to contiguous stereo models, which falls between models, which contain ground control.

238. Aerial triangulation is the simultaneous space resection and space intersection of image rays recorded by an aerial mapping camera. Conjugate image rays projected from two or more overlapping photographs intersect at common points on the ground to define the three-dimensional coordinates of each point. The entire assemblage of image rays is fit to known ground control points in a least-squares adjustment process. When complete, ground coordinates of previously unknown points are determined by the intersection of adjusted rays. Besides the ground coordinates, the location of the camera center (principal center) as well as the orientation of the camera will also be determined.

239. The ground coordinates of fixed photogrammetric points on each stereo model are utilized to scale and level the model during the process of absolute orientation. In DPW, the computed camera location and orientation can also be utilized in absolute orientation.

240. Aerial triangulation is essentially an interpolation tool, capable of extending control points to areas between ground survey control points using several contiguous uncontrolled stereomodels. An aerial triangulation solution should never be extended or cantilevered beyond the ground control. Ground control should be located at the ends of single strips and along the perimeter of block configurations. Within a strip or block, ground control is added at intervals of several stereomodels to limit error propagation in the adjusted pass point coordinates.

241. The principal inputs to the aerial triangulation process are:
    - (a) Aerial Photography;
    - (b) Camera Calibration Data;
    - (c) Ground Control Point Coordinates.

3.2.2 Quality

242. Each of the above inputs will have a profound effect on the quality of the aerial triangulation adjustment. For example, the accuracy (for a given photo scale) is influenced by the following factors:

(a) quality of the original photograph/image (exposure, aircraft movement, image blur, handling);

(b) quality of scanning to convert negative/diapositive into digital file;

(c) quality of the camera (the interior orientation of the camera);

(d) quality and density of ground control;

(e) configuration of the ground control;

(f) shape of the block;

(g) quality of the point marking, transfer and mensuration;

(h) adjustment procedures and algorithms;

(i) adjustments for earth curvature, atmospheric refraction and map projection;

(j) analysis of adjustment results and the application of weights to photogrammetric control points.

3.3 Specifications

3.3.1 Projection, Datum, Coordinates

243. The Geodetic Reference System dedicated to the Rail Baltica Project is RBDatum. Until the RB unified Project dedicated Coordinate System, applicable along the whole alignment of Rail Baltica Project is established, RBDatum will be directly connected to each country coordinate system (see RBDG-MAN-038).

3.3.2 Control Point Configuration

244. Control point configuration, monumentation, targeting and measurement are all prescribed in Specifications for Ground Control Surveys. The salient points describing configuration are summarized hereunder. The ground cover in Baltic Countries is such that horizontal control points should be targeted. Target configurations should be a "+", "T" or "Y". The minimum target sizes should be such that its resultant image on the photograph is no smaller than 15 pixel (or 15 x GSD in meters on ground).

245. Ground control points (GCPs) can either be horizontal control points (HCP) which carry measured X and Y values, vertical control points (VCP) which carry measured Heights only and full ground controls points (GCP) carry measured X, Y values and Heights.

3.3.2.1 With ABGPS and IMU

246. Advancement in ABGPS and IMU technology incorporated in aerial camera system has allowed the camera coordinates and orientation during exposure to be precisely

measured. With a base station within 30km, the accuracy in good conditions can be even up to 3 cm.

247. Additional cross flights (see Figure 16) can be introduced to provide additional strength and accuracy to the block.

248. It is still mandatory to provide GCP-s at the corners and the center of the block to ensure residual bias errors are eliminated and also provide quality checks on the aerial triangulated results.

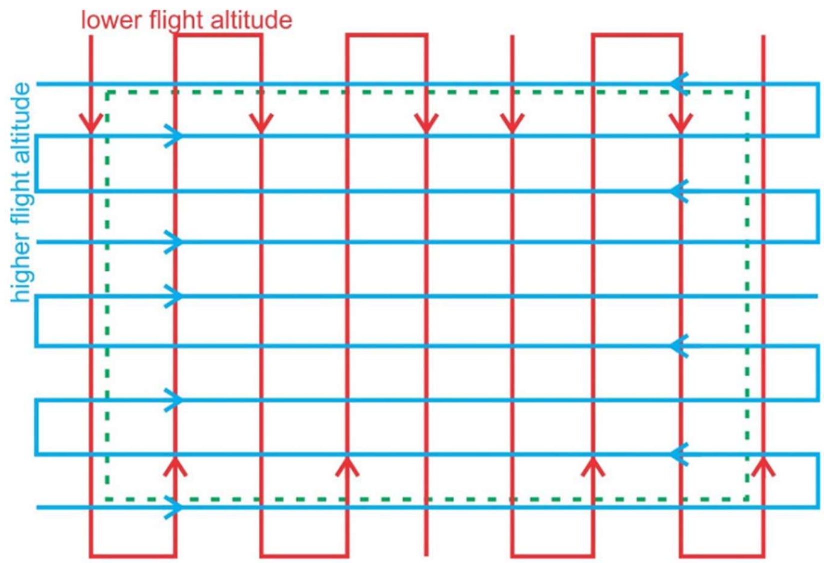


Figure 19. UAV – Scheme for Double Grid (cross) flight plan

3.3.2.2 Check Points

249. The Service may elect to establish checkpoints within the aerial triangulation scheme. In such case the Service will establish the points on the ground. The Contractor shall provide adjusted coordinates for these points for approval prior to finalizing the block adjustment.

3.3.3 Preparation

3.3.3.1 Pass Points

250. Forward pass points are artificially marked points used to locate the same point in successive models along the flight line.

3.3.3.2 Tie Points

251. Tie points are artificially marked points used to locate the same point in adjacent models within different flight lines.

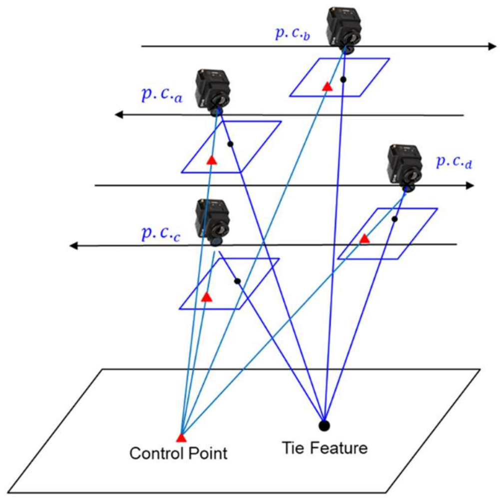


Figure 20. Conceptual basis of bundle block adjustment

3.3.3.3 Softcopy Point Marking and Transfer

252. Aerial triangulation with softcopy simplifies the procedure of pass points processing. The process involved displaying two successive photo images on the monitor screen. The operator then selects arbitrary pass points in the images/photos, and the workstation will automatically assign appropriate image/photo coordinates of that point on each photo/image. If image matching option is enabled, the operator need only select the pass point in one photo and the computer will automatically select the matching point in the other image.

253. Images of adjacent flight line photos can also be displayed for simultaneous tie point marking.

254. The image/photo coordinates of these pass/tie points in the overlap/sidelap area are stored in the computer's database. The marking is only a graphic overlay and does not disturb the original image/photo pixels.

3.3.3.4 Coding

255. A systematic coding scheme shall be employed which facilitates the identification of points according to:
    - (a) location in the Model;
    - (b) flight Line;
    - (c) exposure;
    - (d) point Type.

3.3.4 Adjustment

256. The adjustment shall be fully analytical and performed in two stages:
    - (a) preliminary Strip Formation;

(b) bundle adjustment.

257. Prior to adjustment, inner orientation of the photographs is performed to provide each photograph with photograph coordinates that match the geometry of the image focal plane and perspective center. Affine transformation that matches the fiducial marks with camera focal plane template should be applied to remove scanner errors and lens distortion errors should also be corrected (from camera calibration information). Photographs acquired by digital camera are already inner oriented and will not need this step.

3.3.4.1 Preliminary Strip Formation

258. This step refers to the sequential assembly of independent stereomodels to form a strip unit. The sequential strip formation is a preliminary adjustment that develops initial approximations for the final simultaneous bundle adjustment. The strip formation also serves as a quality control check of the photo and in some cases also ground coordinate data.

(a) Relative orientation of each stereo pair is performed by a least squares adjustment using the collinearity equations and template matching at the selection part of the stereomodel. DPW usually can do this relative orientation step automatically. The stereomodel is created in an arbitrary coordinate system. The photo coordinate residuals should be representative of the point transfer and measuring precision. The photo coordinate residuals should be examined to detect misidentified or poorly measured points.

(b) When stereomodels are joined to form a strip, the pass points shared between models will have two coordinate values, one value in the strip coordinate system and one value in the transformed model coordinate system which is close to the ground coordinates. The coordinate differences or discrepancies between the two values can be examined to evaluate how well the models fit to one another. Outliers can be detected at this stage and corrected.

3.3.4.2 Simultaneous Bundle Adjustment

259. The strips are then joined (in virtual sense) into a block and simultaneous block bundle aerial triangulation must be adjusted by a weighted least squares adjustment method. Adjustment software will form the collinearity condition equations for all the photo coordinate observations in the block and solve for all photo orientation and ground point coordinates in each iteration until the solution converges. The adjustment shall also compensate for earth curvature and atmospheric refraction effects.

260. Least squares adjustment results should be examined to check the consistency of the photo coordinate measurements and the ground control fit. Residuals on the photo coordinates should be examined to see that they are representative of the random error expected from the instrument used to measure them. Residuals should be randomly plus or minus and have a uniform magnitude. Residuals should be checked carefully for outliers and systematic trends. Standard deviation of unit weight computed from the weighted

adjusted residuals should be between 0.5 to 2 times the reference standard deviation used to compute the weights for the adjustment (0.5< 2).

261. Accuracy of aerial analytical triangulation should be measured by the RMSE of the error in each coordinate (X, Y, and Z) direction for the checkpoints if available. The RMSE should be less than flying height in meters (m)/10,000. The maximum residuals of photo coordinates and ground coordinates shall be less than 3 times the respective RMSEs.

Table 9. Important Statistical Measure criteria

Important Statistical Measure	
Standard Deviation of Unit Weight (σ_0)	Between 0.5 to 2.0
RMSE of X,Y,Z coordinates	< flying_height/10,000
Maximum Residuals of Coordinates	< 3 x respective RMSEs

262. The evaluation of the aerial triangulation and adjustment results will not be based solely on the statistical results of the adjustment. The following elements must also be evident in the adjustment:

(a) Proper aerial triangulation technique with respect to control point location and tie point location.

(b) There must be no evidence of a systematic nature to the residuals on either control points or photogrammetric points.

(c) The block must remain structurally sound while meeting a one percent rejection criterion.

3.4 Deliverables

263. A final report shall be delivered detailing:

Table 10. Deliverables

Photography And Control Used	The photograph files, duly annotated shall be delivered
Hardware And Software Employed	This must include all details that pertain to meeting these specifications.
Methodology	
Preliminary Results	
Final Results	The final results, including an accuracy summary
Problems Encountered And Remedial Actions Taken	
Technical Concerns	e.g. weak areas in the block
List Of Control Problems	Points rejected and adjustments to standard weights

264. A final, reproducible computer-generated index map in PDF format will be prepared which identifies all points included in the aerial triangulation and the limits of the photos. The index will also show line and photo numbers. A listing of all adjusted coordinates for all ground control, pass points and tie points.

265. A listing of calculated camera location at time of exposure and orientation parameters.

266. A listing of differences at ground scale between measured and adjusted coordinate values for all control points.

267. A listing of differences at ground scale between measured and adjusted tie photogrammetric points.

268. All deliverables shall be submitted in digital form and hard copy equivalent, in appropriate media and agreed format.