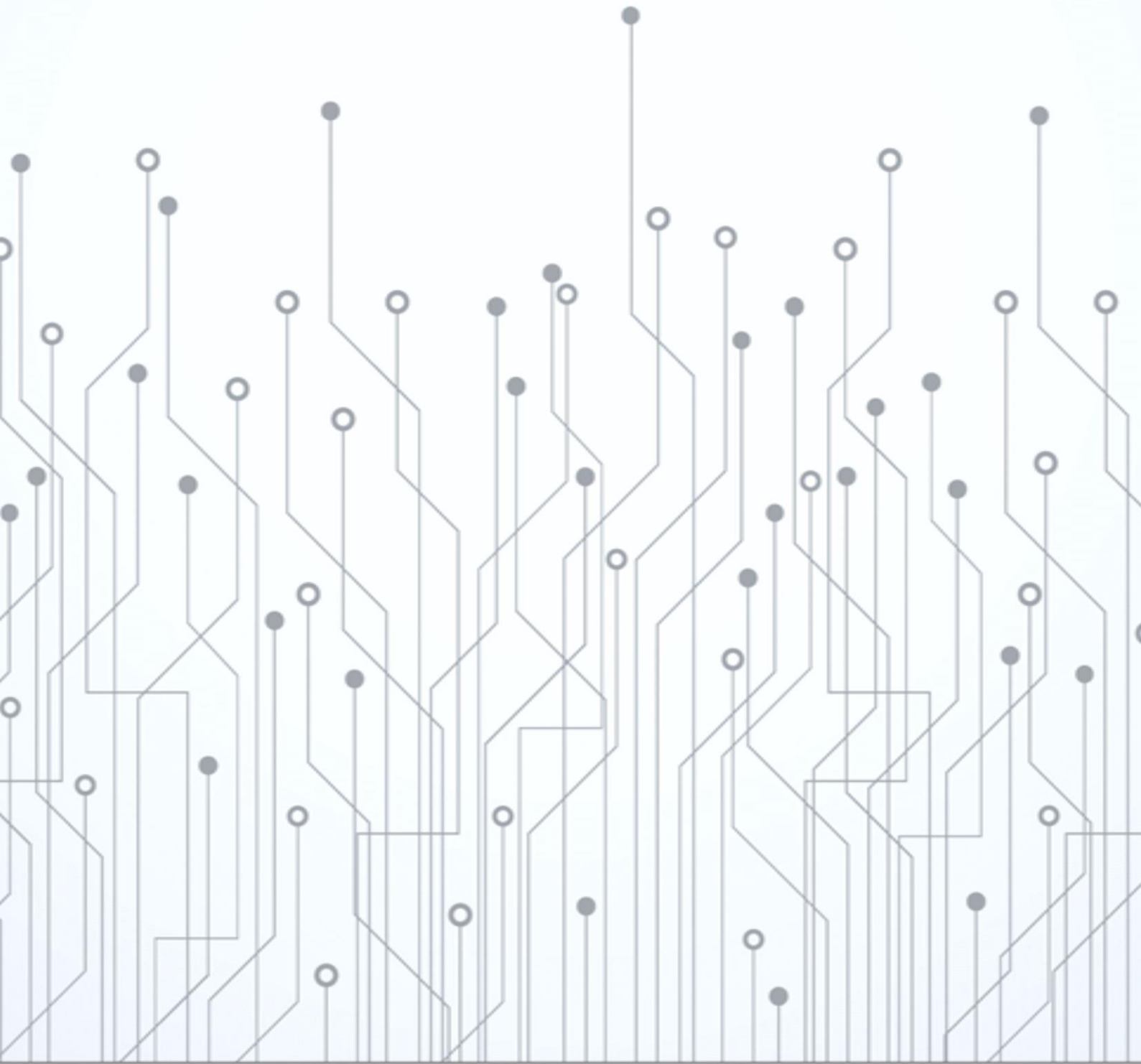




TECHNICAL GUIDELINES FOR GEODESY

V1.0

General Authority for Survey and Geospatial Information



Disclaimer

This document has been developed by the General Authority for Survey and Geospatial Information (GEOSA). Any omissions or errors may please be notified to GEOSA.

These Guidelines have been drafted with reference to various standards and guidelines considered to be international best practices, particularly:

- Federal Geodetic Control Committee (FGCC), 1984. Standards and Guidelines for Geodetic Control Networks. Rockville, Maryland, September 1984 ().
- Federal Geographic Data Committee (FGDC), 2008. Geographic Information Framework Data Content Standard. Part 4: Geodetic Control. Federal Geographic Data Committee Secretariat, Reston, Virginia, 22092. ([Federal Geographic Data Committee, FGDC, 2008](#))
- NGS, 2018. Guidelines for New and Existing Continuously Operating Reference Stations (CORS), National Geodetic Survey, National Ocean Survey, NOAA, Silver Spring, MD 20910. ([National Geodetic Survey, NGS, 2018](#))
- IGS (2023), Continuously Operating Reference Stations in the IGS. International GNSS Service. Version 1.0, October 2023. ([International GNSS Service, IGS, 2023](#))
- ICSM (2014a). Standard for the Australian Survey Control Network, Special Publication 1, Version 2.1, Intergovernmental Committee on Surveying and Mapping, Geodesy Working Group. ([Intergovernmental Committee on Surveying and Mapping, ICSM, 2014](#))
- ICSM (2014b). Guideline for Control Surveys by GNSS, Special Publication 1, Version 2.1, Intergovernmental Committee on Surveying and Mapping, Geodesy Working Group. ([Intergovernmental Committee on Surveying and Mapping, ICSM, 2014](#))
- ICSM (2020a). Guideline for Continuously Operating Reference Stations, Special Publication 1, Version 2.2, Intergovernmental Committee on Surveying and Mapping, Geodesy Working Group. ([Intergovernmental Committee on Surveying and Mapping, ICSM, 2020](#))
- ICSM (2020b). Guideline for the Adjustment and Evaluation of Survey Control, Special Publication 1, Version 2.2, Intergovernmental Committee on Surveying and Mapping, Geodesy Working Group. ([Intergovernmental Committee on Surveying and Mapping, ICSM, 2020](#))
- ICSM (2020c). Guideline for the Adjustment and Evaluation of Survey Control, Special Publication 1, Version 2.2, Intergovernmental Committee on Surveying and Mapping, Geodesy Working Group. ([Intergovernmental Committee on Surveying and Mapping, ICSM, 2020](#))
- NSW Spatial Services (NSW), 2021. Technical Guidelines for NSW Secondary Control Surveys. Department of Customer Service Spatial Services, NSW, Australia. ()
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Foreword

The General Authority for Survey and Geospatial Information (GEOSA) is the national mapping agency of the Kingdom of Saudi Arabia (KSA). These guidelines are a vital framework that aligns the Kingdom's geospatial data management practices with international and national standards. This will help industry, academia, and government bodies in KSA with survey and geospatial data collection and dissemination based on GEOSA existing geodetic guidelines and international best practices. The geospatial guidelines are derived from International and National Standards and then applied to develop guidelines and standard operating procedures (SOPs) for various geospatial and remote sensing data forms. This structured approach ensures that geospatial data collected and managed in KSA adheres to international and national standards, leading to data consistency, reliability, and compatibility.

Future development and growth in the Kingdom of Saudi Arabia (KSA) relies in part on the availability of an accurate and reliable spatial reference system. The authoritative spatial reference system in KSA is the Saudi Arabia National Spatial Reference System (SANSRS). The SANSRS serves as the foundation of KSA's essential positioning infrastructure. This system is linked directly to the International Terrestrial Reference Frame (ITRF). SANSRS forms the basis for a diverse range of applications in the public, government, and commercial sectors, especially where location, positioning, and navigation are critical to those applications. KSA's SANSRS is accurately realized through a well-coordinated network of active Continuously Operating Reference Stations (CORS) and passive geodetic control points. These are complemented by comprehensive information systems for their management and dissemination of related data. This guideline serves as a framework of policies, standards, and guidelines governing the operation and maintenance of this critical infrastructure.

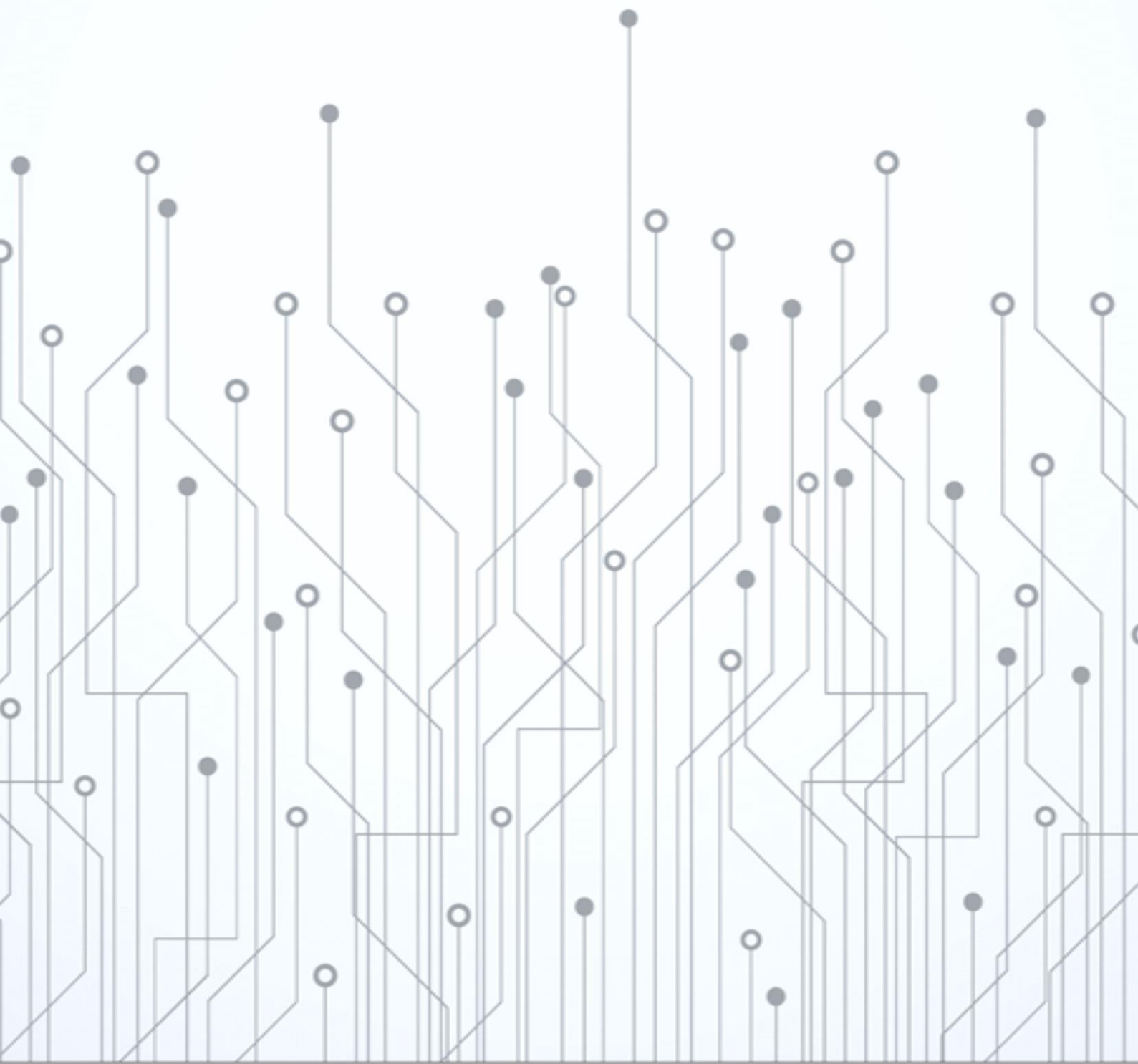
The Geodesy Guidelines for the Kingdom of Saudi Arabia will be maintained by Executive Directorate of Geodesy (EDG), GEOSA and approved by the Office of the President of GEOSA. The guideline covers the following components:

- National Control Networks.
- Geodetic Surveys.
- Geodetic Earth Observation Techniques.
- Geodetic Network Adjustment.

The Guidelines for Geodesy are developed in alignment with already existing and utilized Geodetic Guidelines of EDG (Technical Summary for Saudi Arabia National Spatial Reference System, GEOSA, 2022 and Geodetic Survey Guidelines, GEOSA, 2024). Also, they have been aligned with the National Geospatial Data Policies and Standards for the Kingdom of Saudi Arabia (). Additionally, references to other guidelines within this series, such as the Guidelines for Land Survey () and the Guidelines for Hydrography () have been incorporated where relevant throughout this document.

Changes to this Guideline will be instructed by the President of GEOSA, as improvements or amendments become necessary or as required.

1. Introduction



Scope and Objectives of the Guideline

The purpose of this Guideline is to set out the minimum requirements for the determination of one-, two- or three-dimensional position, parameters of Earth gravity potential field, their temporal variations, and associated accuracies of survey control marks in the Kingdom of Saudi Arabia.

This Guideline prescribes requirements for control surveys that define, extend, improve, densify, or otherwise connect to the SANSRS. The control surveys can be conducted in 1D (vertical only), 2D (horizontal only), or 3D (both horizontal and vertical). The following control surveys are within the scope of this Guideline – Geodetic Datum Control Surveys and General-Purpose Control Surveys. These surveys are defined below.

Geodetic Datum Control Surveys define, extend, or improve the SANSRS. These control surveys are included in the SANSRS network adjustments to allow for the most rigorous estimation and testing of position and accuracy for new and existing survey control marks.

General Purpose Control Surveys are not included in SANSRS adjustments but connect to the SANSRS to estimate the position and accuracy of new survey control marks relative to the SANSRS.

The provisions in this Guideline for expressing accuracy have been developed primarily for Datum Control Surveys, but are also intended to be adopted, where possible, for all forms of General-Purpose Control Surveys.

Government and private sector organizations undertaking Geodetic Datum Control Surveys must comply with this Guideline.

More details on the various aspects of how to use this Guideline, together with additional technical details and commentary, are provided in the SANSRS Technical Summary and Geodetic Survey Guidelines listed in the reference section.

Terms and Definitions

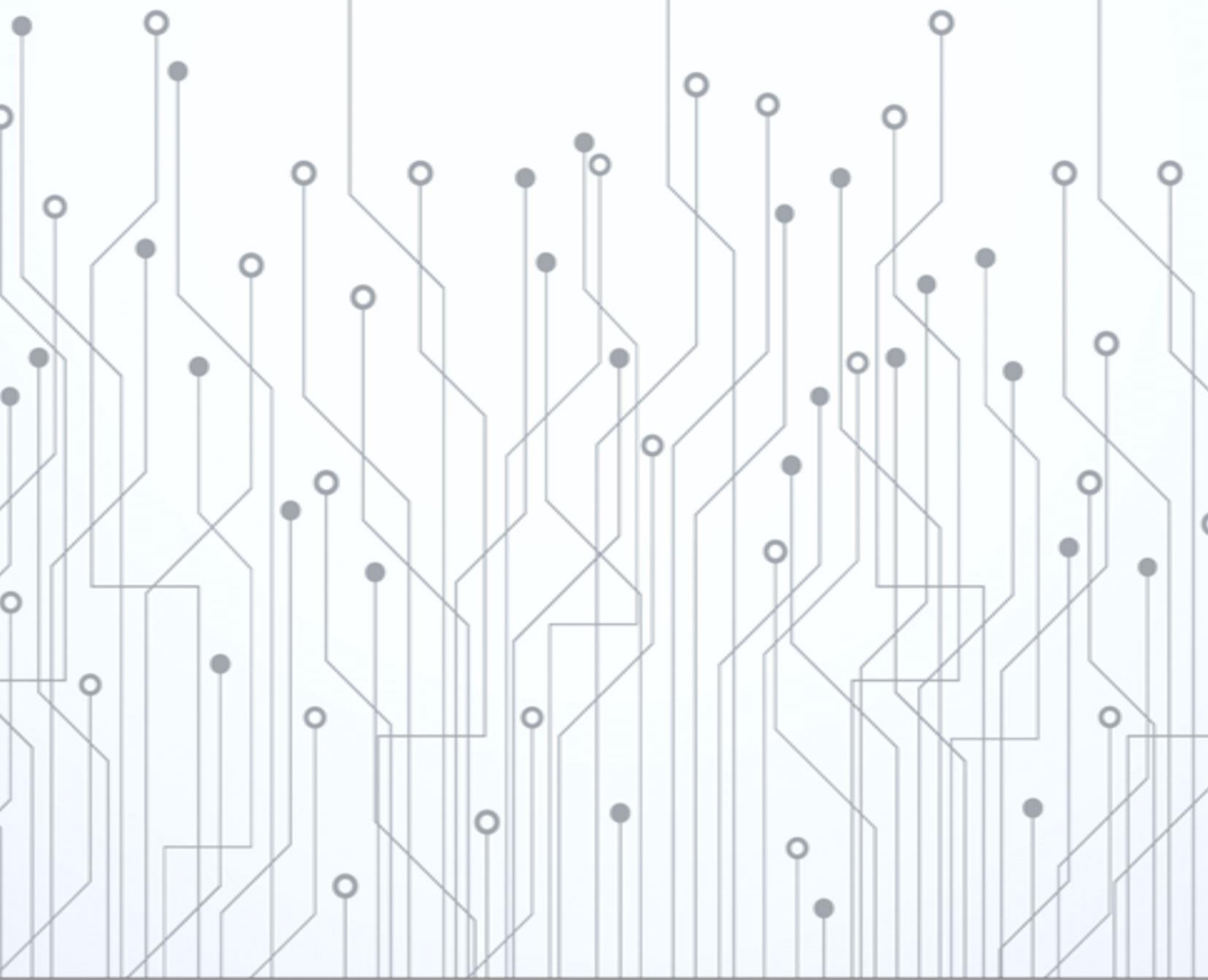
Table 1: Terms and Definitions

Term	Definition
Accuracy	The level of closeness of an estimated value – measured or computed – of a quantity to its true or accepted value.
Class	Class assignment is based on the accuracy of a geodetic reference point and the consistency of that point with other points within the network.
Control Point	High-accuracy coordinated points are used in determining the location of other points.
Control Survey, Geodetic Datum	A survey that defines, extends, or improves the SANSRS. These surveys are included in SANSRS adjustments to allow for the most rigorous estimation and testing of position and accuracy.
Control Survey, General Purpose	A survey that connects to the SANSRS to estimate the position and accuracy of new survey control marks relative to the SANSRS. Such surveys are not included in SANSRS adjustments.
CORS	Continuously Operating Reference Station. A survey control mark hosting a permanent GNSS station.
Geodetic Datum	An official, fully defined, spatial reference system or surface to which measurements and/or coordinates upon the Earth may be defined and related.
Geodetic Control	Set of control points whose coordinates are established by geodetic surveying techniques such as triangulation, traverse, geodetic leveling, or GNSS survey.
Geodetic Reference point	A geodetic control point whose horizontal and, or vertical coordinates have been accurately determined using geodetic and, or gravity surveying methodology.

Geoid	The equipotential surface of the Earth's gravity field which best fits global mean sea level.
GNSS	A Global Navigation Satellite System(s) – a generic term for satellite-based positioning systems.
Horizontal Geodetic Control	Control points for which horizontal coordinates have been accurately determined can be identified with physical points on the Earth and used to provide horizontal coordinates for other surveys.
IGS	International GNSS Service - An international federation of agencies that pool resources to operate a global CORS network whose data is used, amongst other purposes, to generate precise GNSS products in support of Earth science research.
ITRF	International Terrestrial Reference Frame - a realization of the International Terrestrial Reference System (ITRS) produced by the International Earth Rotation and Reference Systems Service (IERS).
KSA-GRF17	Current geodetic datum for KSA. KSA-GRF17 is a three-dimensional, static (plate-fixed) reference frame coincident with the ITRF2014 at the reference epoch of 1st January 2017.
KSA-VRF14	Current vertical reference frame for KSA. KSA-VRF14 is an orthometric height datum that is based on satellite altimetry and Gravity field and steady-state Ocean Circulation Explorer (GOCE) data, as well as in situ observations from tide gauges, terrestrial national gravity, and leveling networks.
KSA-GEOID21	Current geoid model for KSA. KSA-GEOID21 is a hybrid geoid model consisting of a gravimetric geoid model of the KSA and a geometric correction surface that distorts the gravimetric geoid model to the KSA-VRF14.
Local Accuracy	Correctness of the coordinates of a control point relative to the coordinates of other directly connected, adjacent control points.
Measurement	A measurement is an observed value, the outcome of a repeated set of observations, or the result of processing such observations.
Network Accuracy	Correctness of the coordinates of a control point with respect to the geodetic datum.
Order	Order is assigned on the basis of the contribution of the geodetic reference point to the formation of the network and the propagation of the associated reference frame. The assignment of Order is not directly related to the accuracy of the geodetic reference point.
Precision	A term used to quantify the variability of a measurement or computed value. If several measurements are taken repeatedly to represent the same quantity, precision is used to refer to the degree of closeness or conformity of those measurements to each other.
Reference Ellipsoid	Ellipsoid of specified dimensions and associated with a geodetic reference system or a geodetic datum
SANSRS	Saudi Arabia National Spatial Reference System – is KSA's authoritative, reliable, high-accuracy spatial referencing system. It includes the KSA-GRF17, KSA-VRF17, and KSA-GEOID21 datums and geoid models.
Vertical Geodetic Control	Control points with accurately determined orthometric heights and/or ellipsoidal heights identified with physical points on the Earth that can be used to provide elevations for other surveys.

2. Normative Elements

National Geodesy Technical Guidelines



2.1 Quantifying Accuracy

2.1.1 Accuracy Classification (GEOSA Conventions)

Accuracy is defined as the level of closeness of an estimated value – measured or computed – of a quantity to its true or accepted value.

Current GEOSA conventions classify the accuracy of National Control Networks and their individual geodetic reference points according to Class and Order.

2.1.1.1 Class

The assignment of Class is based on the accuracy (as defined in [Section 2.1.1](#)) of a geodetic reference point and the consistency of that geodetic reference point with other geodetic reference points within the network. Thus:

- A geodetic reference point of a certain Class is consistent with all other geodetic reference points of the same Class within the network and its associated reference frame.
- A geodetic reference point of a certain Class is consistent with, and of the same Class as all other geodetic reference point within the survey(s) that established the geodetic reference point.

2.1.1.2 Order

The assignment of Order is not directly related to the accuracy of a geodetic reference point. The order is assigned based on the contribution of a geodetic reference point to the formation of the network and the propagation of the associated reference frame. Thus:

- A geodetic reference point considered high accuracy (e.g. Class 1) and that provides a minimal contribution to the propagation of the reference frame (e.g. a small-scale deformation monitoring network) would be assigned a low order.
- A geodetic reference point considered medium accuracy (e.g. Class 2) and that is critical to the propagation of the reference frame (e.g. a leveling junction point) would be assigned a high order.

2.1.1.3 Assigning Class & Order

The assignment of Class and Order is a complex task that requires significant knowledge and experience of a network, its geodetic reference points, and the associated surveys (including historical information). Details for assigning Class and Order for each national control network and associated geodetic reference points are provided in Sections 2.3.1.5.1 **Assigning Class**, 2.3.2.5.1 **Assigning Class**, 2.3.3.5.1 **Assigning Class**, and 2.3.4.5.1 **Assigning Class**

Additional details on assigning Class and Order within each of the National Control Networks can be found in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.1.2 Accuracy Classification (International Best Practice)

Current International Best Practice (IBP) for the quantification and classification of accuracy (in the context of geodetic networks and geodetic activities) is based on the ISO definition for the description of uncertainty as described in the GUIDE TO THE EXPRESSION OF UNCERTAINTY IN MEASUREMENT ([Joint Committee for Guides in Meteorology, JCGM, 2020](#)).

It is anticipated that the GEOSA will transition to this definition in the future. To aid this transition, the current IBP accuracy standards are summarized below. Note that the underlying definition for how accuracy is quantified is similar to [Section 2.1.1](#), but that a simpler and more transparent method for classifying accuracy is utilized.

2.1.2.1 Definition

The accuracy of a parameter (e.g. 3D position, physical height) is quantified by a numerical value (with appropriate SI units) representing the 95% confidence level of the parameter. The parameter that the accuracy is associated with is assumed to be free of gross and systematic errors.

2.1.2.2 Local Accuracy

The accuracy of a parameter (e.g. 3D position of a geodetic reference point) is relative to the survey in which it was observed, free from the influence of any imprecision or inaccuracy in the underlying reference frame. Therefore, local accuracy reflects only the accuracy resulting from survey measurements, measurement precisions, network geometry, and the choice of constraints.

2.1.2.3 Network Accuracy

The accuracy of a parameter (e.g. 3D position of a geodetic reference point) with respect to the defined reference frame. Network accuracy represents the combined accuracy of the existing reference frame realization and the new survey. That is, network accuracy includes local accuracy as well as the accuracy of the existing survey control marks to which a new control survey is connected.

2.1.2.4 Implementation

A least squares adjustment must be used to estimate and test survey accuracy. For local accuracy, a minimally constrained adjustment must be used. For network accuracy a fully constrained adjustment must be used, however, the control should not be fixed, but rather constrained using the variance matrix from the national adjustment.

Both local and network accuracies should be provided in appropriate SI units at the 95% confidence level.

Local accuracy for horizontal and vertical geodetic control points is similar to the current GEOSA accuracy methodology using the Class system since they both describe the relative accuracy between points. Hence, the current Class methodology can be converted into local accuracy by taking the average length of the line, using the currently defined accuracy of the points, and converting that into a value in meters.

Example vertical survey is shown below. Note that the Class for Geodetic Levelling is taken from Section 2.4.2.2...

- Second-order, class 2 leveling survey (i.e., $1.3 \text{ mm } \sqrt{\text{km}}$) with an average benchmark spacing of 1.5 kilometers:

$$0.0013 \times \sqrt{1.5} = 0.0016 \text{ m}$$

A similar mathematical strategy for converting Class/Order to Network accuracy does not exist.

2.2 Connection to SANSRS

Geodetic and general purpose survey control points within the KSA that are established via geodetic activities () or general purpose control surveys as prescribed in the Guidelines for Land Survey for the Kingdom of Saudi Arabia () for the SANSRS must be realized relative to one (or more) components of one unified SANSRS.

2.2.1 National Geodetic Reference Frame – KSA-GRF17

For SANSRS, the geodetic reference frame is the KSA Geodetic Reference Frame 2017 (KSA-GRF17). KSA-GRF17 is a three-dimensional, static (plate-fixed) reference frame coincident with the International Terrestrial Reference

Frame (ITRF) 2014 at the reference epoch of 1st January 2017. The reference ellipsoid for KSA-GRF17 is the Geodetic Reference System 1980 (GRS80).

The coordinates (2D or 3D) of geodetic and general-purpose survey geodetic reference points within the KSA and its territories must be realized in terms of KSA-GRF17.

If realization in terms of KSA-GRF17 is not possible, coordinates may be realized in ITRF2014 and transformed to KSA-GRF17. Transformation parameters are available in the SANSRS Technical Summary ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#)) and an online tool to perform transformations is available at: <https://www.geosa.gov.sa/En/EService/pages/gds.aspx>.

For technical details on the definition and realization of KSA-GRF17, refer to the SANSRS Technical Summary ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#)).

2.2.2 National Vertical Reference Frame – KSA-VRF14

For SANSRS, the vertical reference frame is the KSA Vertical Reference Frame 2014 (KSA-VRF14). KSA-VRF14 is an Helmert orthometric height datum that is based on satellite altimetry and Gravity field and steady-state Ocean Circulation Explorer (GOCE) data, as well as in situ observations from tide gauges, terrestrial national gravity and leveling networks ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#)).

The orthometric height (physical height) of geodetic and general-purpose survey geodetic reference points within the KSA and its territories must be realized in terms of KSA-VRF14.

In circumstances where orthometric height in KSA-VRF14 is realized by the Global Navigation Satellite System (GNSS) Leveling ([Section 2.4.3](#)) the KSA National Geoid Model 2021 (KSA-GEOID21) must be used to transform KSA-GRF17 ellipsoid heights to KSA-VRF14 orthometric heights. For technical details on the definition and realization of KSA-VRF14, refer to the SANSRS Technical Summary ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#)).

2.2.3 National Geoid Model – KSA-GEOID21

For SANRS, the current geoid model is the KSA National Geoid Model 2021 (KSA-GEOID21). KSA-GEOID21 is a hybrid geoid model ([Grebenitcharsky et al., GEOSA, 2023](#)) consisting of a gravimetric geoid model (Vergos et al., GEOSA, 2023) of the KSA and a geometric correction surface that distorts the gravimetric geoid model to the KSA-VRF14. As such, the KSA-GEOID21 enables the transformation of KSA-GRF17 ellipsoid heights to KSA-VRF14 orthometric heights and vice-versa.

The KSA-GEOID21 must be used when transforming a KSA-GRF17 ellipsoid height to a KSA-VRF14 orthometric height (e.g. when conducting GNSS/Leveling). The reverse case (KSA-VRF14 to KSA-GRF17) also applies.

The KSA-GEOID21 should only be used to perform transformations within the boundaries of the model. For technical details on the computation of KSA-GEOID21 and its geographic extent, refer to the Technical Summary for SANSRS ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#)).

2.3 National Control Networks

The National Control Networks of the KSA specified by GEOSA are:

- The National Geodetic Network (NGN), consisting of:
 - The KSA-CORS (Continuously Operating Reference Stations) Network (or Active NGN).
 - The Passive National Geodetic Network (Passive NGN).
- The National Vertical Network (NVN).
- The National Gravity Network (NGrN).

The status of these networks as of September 2022 is shown in Figure 1, Figure 2, and Figure 3 respectively. Additional details on the status of each network are provided below.

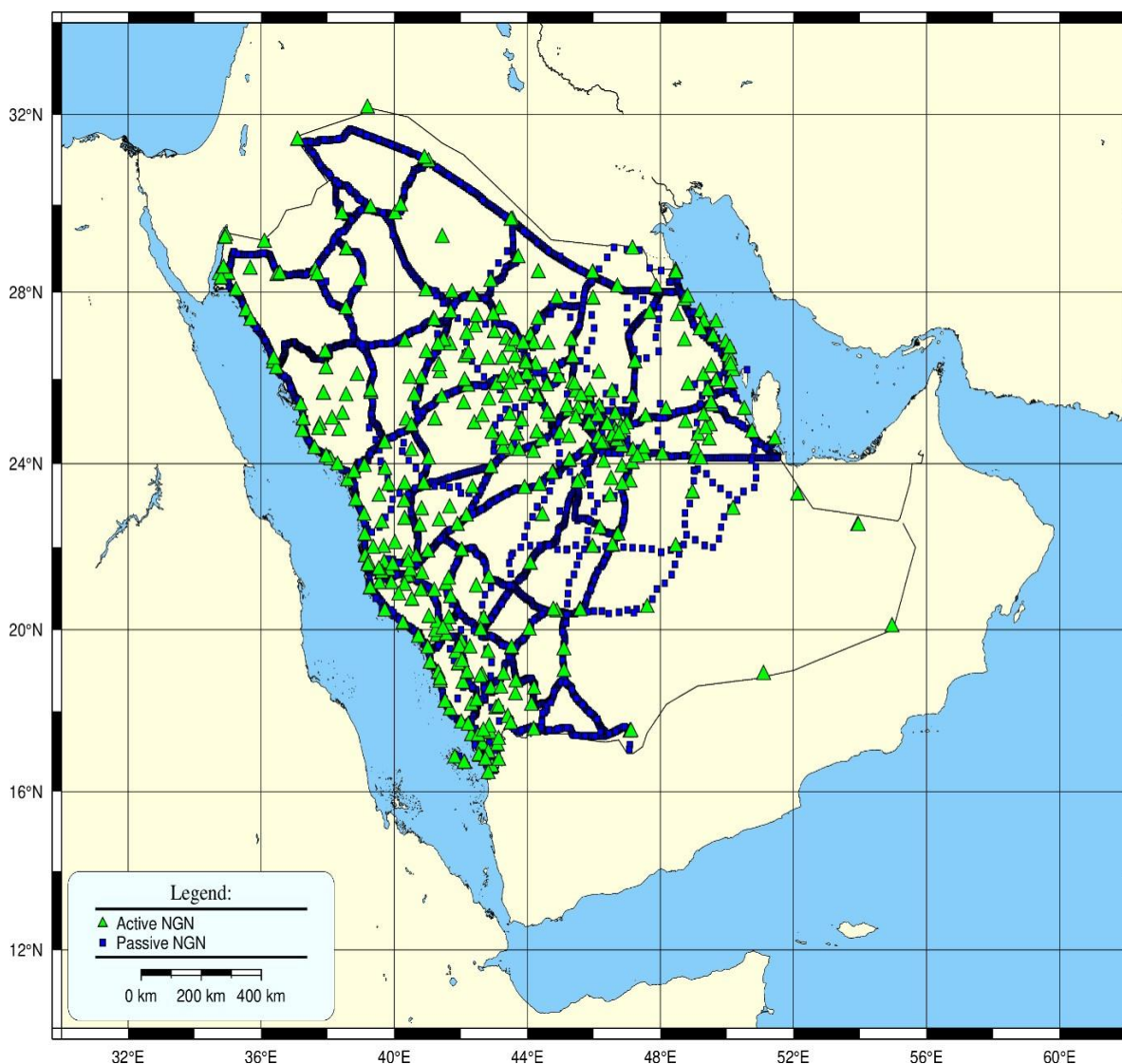


Figure 1: National Geodetic Networks (September 2022) (Source: SANSRS Technical Summary ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#)))

2.3.1 KSA-CORS Network

2.3.1.1 Definition

The KSA-CORS Network is a network of GNSS Continuously Operating Reference Stations (CORS) that serves as the primary connection of KSA-GRF17 to the International Terrestrial Reference Frame (ITRF). The KSA-CORS Network is an example of an Active National Geodetic Network (Active NGN) and, as such, it physically realizes KSA-GRF17 throughout the KSA.

Each CORS within the KSA-CORS Network continuously tracks and observes signals from all available GNSS satellites. The resulting observation data is streamed (in real-time) to centralized computing facilities where the data is processed to generate products and services that support a wide variety of post-processed and real-time positioning applications at the centimeter level.

The observation data continuously accumulated from the KSA-CORS Network is critical to the development, propagation, and maintenance of the KSA-GRF17. Similarly, the real-time services generated from the KSA-CORS Network play a pivotal role in providing end-users with access to the KSA-GRF17.

The CORS that comprises the KSA-CORS Network do not generally serve concurrently as geodetic reference points within other networks (e.g. NVN, NGrN) due to their role and the nature of their construction. However, establishing geodetic reference points of other networks in the vicinity of a CORS as well as precise interconnection of geodetic reference points by measurement, is strongly recommended.

2.3.1.2 Network Structure

The National CORS network contains physical geodetic reference points with active GNSS receivers spaced at regular intervals and organized into sub-networks based on Class.

2.3.1.2.1 Geodetic Reference Point Spacing

The spacing of CORS within the KSA-CORS is recommended to be 70 km .

2.3.1.2.2 Sub-Networks

A subset of CORS may be designated as a sub-network of the KSA-CORS. CORS should be selected for inclusion in the sub-network based on common criteria (e.g. receiver quality) or purpose (e.g. autonomous vehicle testing).

Geodetic reference points within the sub-network are not bound by the requirements of [Section 2.3.1.2.1](#) and may be spaced at any interval.

Currently, three sub-networks exist within the KSA CORS (Table 2).

Table 2: KSA CORS Sub-Networks (as of March 2024)

Sub-Network	CORS	Selection Criteria
Fundamental Order	40	KSA stations which were utilized to determine transformation parameters between ITRF2014 and KSA-GRF17.
Primary Order	292	KSA stations which were included in the determination of the KSA-GRF17.
Secondary Order	77	GEOSA stations (currently) which were installed after the KSA-GRF17 solution and are provided with coordinates in KSA-GRF17 determined based on Fundamental/Primary stations.

2.3.1.2.3 Other Networks

The geodetic reference points that comprise other networks (NVN, NGrN) shall not be considered part of the KSA-CORS Network.

2.3.1.2.4 Status

The structure of the KSA-CORS in September 2022 as shown in Figure 1.

The current structure of the KSA-CORS is available at <https://ksacors.geosa.gov.sa>.

2.3.1.3 Site Considerations

A CORS is a complex and expensive piece of geodetic infrastructure. The establishment of new, or the maintenance of existing CORS must consider elements that include, but are not limited to:

- Network design.
- GNSS observing environment (e.g. obstructions, radio interference).

- Accessibility.
- Security and resilience.
- Power and communications.
- GNSS equipment and other sensors.
- Operation (including maintenance).

Guidelines and guidelines relating to the establishment and maintenance of CORS can be separated into three categories based on the intended contribution of the CORS.

Table 3: Guidelines and Guidelines Relating to the Establishment and Maintenance of CORS

Contribution	Description	Primary Guidelines	Secondary Guidelines
International	The primary contribution of the CORS is to international geodetic efforts. The CORS is to be included in the IGS Network.	IGS (2023) Guidelines for Continuously Operating Reference Stations in the IGS	N/A
National/ Regional	The primary contribution of the CORS is to geodetic efforts within the KSA and the surrounding region. The CORS is to be included in the KSA-CORS Network.	ICSM (2020) Guideline for Continuously Operating Reference Stations Special Publication 1	NGS (2018) Guidelines for New and Existing Continuously Operating Reference Stations (CORS)
State / Local	The primary contribution of the CORS is localized or limited. The CORS may not be included in the KSA-CORS Network.	ICSM (2020) Guideline for Continuously Operating Reference Stations Special Publication 1	NGS (2018) Guidelines for New and Existing Continuously Operating Reference Stations (CORS)

Note that a CORS designed and constructed to satisfy a particular scale of contribution (e.g. International) can contribute at smaller scales (e.g. National). Generally, CORS designed and constructed for smaller scales (e.g. National) do not contribute at larger scales (e.g. International).

An existing CORS can be upgraded (e.g. GNSS equipment, power, communications) to meet a higher guideline/contribution.

2.3.1.4 Realization

The 3D position of a KSA-CORS must be realized in KSA-GRF17 using GNSS measurement techniques, network adjustment, and existing KSA-CORS.

- The GNSS measurement and network adjustment techniques utilized must conform with at least the Class 2 guidelines described in .
- The 3D position must be derived from at least three existing KSA-CORS using GNSS observation data of at least one week in duration (7 days x 24 hours) as recommended in the IBP reference of ICSM CORS guidelines.
- The 3D position must be accompanied by evidence that the accuracy requirements ([Section 2.3.1.5](#)) have been met.

2.3.1.5 Accuracy Requirements

When realizing the 3D position of a KSA-CORS within KSA-GRF17 the accuracy of the 3D position, calculated from the results of a fully constrained least squares network adjustment, must not exceed:

Horizontal Position:	0.010 m (95% Confidence)
Ellipsoidal Height:	0.020 m (95% Confidence)

2.3.1.5.1 Assigning Class

If the requirements of [Section 2.3.1.5](#) are met, the Class of the geodetic reference point is assigned as shown in Table 3. **Error! Reference source not found.** below:

Table 3: Assigning Class (KSA-CORS Network)

Class	Horizontal Position (95%)	Ellipsoid Height (95%)
0	0.004	0.008
1	0.006	0.012
2	0.010	0.020

2.3.1.6 Monitoring

By definition, a GNSS CORS continuously observes and records GNSS observation data. As such, the 3D position of CORS within the KSA-CORS can be monitored continuously (at various time scales).

Note that monitoring in this context refers only to the 3D position of the CORS within the KSA-GRF17. The monitoring of other parameters related to CORS (e.g. data latency) is not within the scope of this Guideline.

2.3.1.6.1 Annual Monitoring

The KSA-GRF17 3D position of each CORS within the KSA-CORS network must be verified on an annual basis by re-computing the 3D position in accordance with the requirements of [Section 2.3.1.5](#).

In the event that:

- The re-computed 3D position fails to meet the accuracy requirements set out in [Section 2.3.1.5](#); or
- The difference between the original and re-computed 3D position exceeds the threshold propagated from the accuracy requirements specified in [Section 2.3.1.5](#).

The CORS should be removed from the KSA-CORS (including any sub-networks) until the discrepancy is resolved.

2.3.1.6.2 Continuous Monitoring

For CORS within the KSA-CORS that stream GNSS observation data to a centralized processing facility, it is strongly recommended that:

- Operators utilize the monitoring tools within existing software products (e.g. Network RTK Software) to implement position alerts/notifications derived from the accuracy thresholds specified in [Section 2.3.1.5](#),
- Operators collate the GNSS observation data daily. The collated data should be delivered, daily, to an independent monitoring service for analysis.

2.3.1.6.3 Special Events

A special event is defined as any occurrence that could reasonably be considered to impact the 3D position of a CORS within the KSA-CORS Network. Examples of such events include:

- Seismic or other geophysical events.
- Damage to CORS or supporting infrastructure.
- Construction in the vicinity of the CORS.
- Replacement of the GNSS antenna.

The impact of any such event on the 3D position of the CORS should be ascertained using either:

- An analysis of continuous monitoring data ([Section 2.3.1.6.2](#)), or
- An analysis of the 3D position of the CORS before and after the event, based on the requirements in [Section 2.3.1.6.1](#).

If the analysis indicates a significant impact on the 3D position of the CORS, then the 3D position of the CORS must be re-computed in accordance with [Section 2.3.1.5](#).

2.3.1.7 Publication

The 3D position, accuracy, and relevant metadata for all CORS within the KSA-CORS must be made available to the general public via a findable and accessible medium.

The recommended medium is an online website or portal.

The products and services generated by operators are not the subject of this guideline. Guidelines relating to products and services supplied by CORS Networks are available in the guidelines referenced in .

2.3.2 Passive National Geodetic Network

2.3.2.1 Definition

The Passive National Geodetic Network (Passive NGN) is a network of passive geodetic points that physically implement KSA-GRF17 throughout the KSA.

The Passive NGN densifies the KSA-CORS Network and provides access to KSA-GRF17 in situations where the KSA-CORS Network is unable to provide access to KSA-GRF17 (e.g. communications outage, GNSS-denied environments when utilizing traditional surveying equipment).

The passive geodetic points that comprise the Passive NGN may also serve concurrently as geodetic reference points within other networks (specifically, NVN, NGrN).

2.3.2.2 Network Structure

The Passive NGN network contains physical geodetic reference points spaced at regular intervals and organized into sub-networks based on Class.

2.3.2.2.2 Sub-Networks

A subset of geodetic reference points may be designated as a sub-network of the Passive NGN. Geodetic reference points should be selected for inclusion in the sub-network based on common criteria (e.g. geodetic reference point stability) or purpose (e.g. deformation monitoring).

Geodetic reference points within the sub-network are not bound by the requirements of [Section 2.3.2.2.1](#) and may be spaced at an interval appropriate to the purpose of the sub-network.

Currently, three sub-networks exist within the Passive NGN as per

Table 4 below.

Table 4: Passive NGN Sub-Networks (as of March 2024)

Sub-Network	Geodetic Reference Points	Selection Criteria	Recommended spacing [km]
Fundamental Order	34	Included in KSA-GRF17 realization. Class 0 GNSS survey.	350
Primary Order	646	No direct connection to KSA-GRF17. Class 1 GNSS survey, 7 parameter transformation from GDMS only.	70
Secondary Order	3645	Direct connection to KSA-GRF17. Class 2 GNSS survey	20

2.3.2.2.3 Other Networks

The active geodetic points that comprise the KSA-CORS Network shall not be considered part of the Passive NGN.

The geodetic reference points that comprise other networks (NVN, NGrN) may be considered part of the Passive NGN provided they meet the requirements set out in [Section 2.3.2.4](#).

2.3.2.2.4 Status

The structure of the Passive NGN in September 2022 is shown in Figure 1.

The current structure of the Passive NGN is available at the following website:
<https://www.geosa.gov.sa/En/Products/Geodesy/Pages/default.aspx>.

2.3.2.3 Site Considerations

Passive geodetic points should be established and maintained in accordance with the following guidelines:

2.3.2.3.1 Site Location Selection

New Passive NGN geodetic reference points need to be:

- Installed in solid rock or stable ground such that the geodetic reference point is unlikely to be subject to localized displacement (natural or anthropogenic) or periodic movement (e.g. seasonal movement). If solid rock or stable ground is unavailable the installed geodetic reference point should penetrate the

unstable surface soil to the depth of refusal (solid rock or stable ground). Examples of geodetic reference points suitable for use in these scenarios are available in [Annex A](#).

- Installed in a location where the geodetic reference point is unlikely to be disturbed, damaged, removed, or to constitute a hazard.
- Installed in a location that maximizes the utility of the geodetic reference point within the NGN, NVN, and NGrN.
- Installed in a location that provides (and will continue to provide) an optimal GNSS observing environment as described in [Section 2.4.1.3](#).
- Installed in a location that is accessible, thereby allowing for the proper use and maintenance of the geodetic reference point.

2.3.2.3.2 Identification

New Passive NGN geodetic reference points need to be:

- Permanently and clearly marked with a unique identifier to ensure unambiguous identification. A station identifier should be engraved or stamped on the geodetic reference point, or a durable tag with the identifier firmly attached.
- Accompanied by a marker post or indicator if the geodetic reference point may be difficult to locate.
- Recorded using geotagged digital photos showing the geodetic reference point and its surrounds.
- Recorded on an annotated aerial image or digital recovery sketch that identifies the location of the geodetic reference point in relation to surrounding features.

2.3.2.3.3 Monumentation

New Passive NGN geodetic reference points need to be:

- Constructed of high-quality, durable, corrosion-resistant materials.
- Constructed and installed according to the relevant design drawings.
- Compliant with any planning, construction, occupational health and safety, or other applicable codes, regulations, or laws that apply in the KSA.

Additional details on materials, designs, and installation procedures can be found in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.3.2.3.4 Maintenance

Routine maintenance of the geodetic reference points and their surroundings is required to ensure that they remain fit for purpose. Routine maintenance, in the form of a physical inspection of the geodetic reference point and surroundings, shall occur:

- Once every five years.
- In response to reports of damaged, destroyed, or missing geodetic reference points.
- In response to geophysical events
- During re-observation of an existing geodetic reference point (see [Section 2.3.2.6](#)).

The purpose of any actions undertaken during routine maintenance shall be to restore the geodetic reference point and its surroundings to a fit-for-purpose state per these Guidelines.

If a geodetic reference point or its surroundings are unable to be restored to a fit-for-purpose state, a suitable replacement should be installed, subject to the requirements of this section.

2.3.2.4 Realization

The 3D position of a Passive NGN point shall be realized in KSA-GRF17 using GNSS measurement techniques, network adjustment, and existing points within the NGN.

- The GNSS measurement and network adjustment techniques utilized must conform with at least the Class 2 guidelines described in .
- The 3D position shall be derived from at least two existing Passive NGN points and/or at least two KSA-CORS.
- The 3D position must be accompanied by evidence that the accuracy requirements ([Section 2.3.2.5](#)) have been met.

2.3.2.5 Accuracy Requirements

When realizing the 3D position of a Passive NGN point within KSA-GRF17 the accuracy of the 3D position, computed from the results of a fully constrained least squares adjustment, must not exceed:

Horizontal Position:	0.010 m (95% Confidence)
Ellipsoidal Height:	0.020 m (95% Confidence)

2.3.2.5.1 Assigning Class

If the requirements of [Section 2.3.2.5](#) are met, the Class of the Passive NGN geodetic reference point is assigned as follows:

Table 5: Assigning Class (Passive NGN)

Class	Horizontal Position (95%)	Ellipsoid Height (95%)
0	0.004	0.008
1	0.006	0.012
2	0.010	0.020

2.3.2.6 Monitoring

2.3.2.6.1 Periodic Monitoring

At least every 10 years the KSA-GRF17 3D position of each Passive NGN geodetic reference point with seismic/geophysical, technogenic or local movements shall be verified by re-observing and re-computing the 3D position in accordance with the requirements of [Section 2.3.2.4](#).

In the event that:

- The re-computed 3D position fails to meet the accuracy requirements set out in [Section 2.3.2.5](#); or
- The difference between the original and re-computed 3D position exceeds accuracy thresholds propagated from the accuracy requirements specified in [Section 2.3.2.5](#).

the geodetic reference point should be removed or at least re-classified from the Passive NGN (including any sub-networks) until such time as the discrepancy is resolved.

2.3.2.6.2 Special Events

A special event is defined as any occurrence that could reasonably be considered to impact the 3D position of a Passive NGN geodetic reference point. Examples of such events include:

- Seismic or other geophysical events.
- Damage to the geodetic reference point or supporting infrastructure.

- Construction in the vicinity of the geodetic reference point.

The impact of any such event on the 3D position of the Passive NGN geodetic reference point should be ascertained through an analysis of the 3D position of the Passive NGN geodetic reference point before and after the event, based on the requirements in [Section 2.3.2.6.1](#).

If the analysis indicates a significant impact on the 3D position of the Passive NGN geodetic reference point, the 3D position of the Passive NGN geodetic reference point must be re-computed and re-classified in accordance with [Section 2.3.2.4](#).

2.3.2.7 Publication

The 3D position, accuracy, and relevant metadata for all geodetic reference points within the Passive NGN must be made available to the general public via a findable and accessible medium.

The recommended medium is an online website or portal.

2.3.3 National Vertical Network

2.3.3.1 Definition

The National Vertical Network (NVN) is a network of passive geodetic benchmarks that physically implement KSA-VRF14 throughout the KSA.

The primary purpose of the NVN is to realize the National Vertical Reference Frame by providing users with accurate physical heights in KSA-VRF14. In addition, the NVN is a fundamental source of information for the determination of the national geoid model and for the monitoring of vertical crustal deformation.

The passive geodetic benchmarks that comprise the NVN may also serve concurrently as monuments within other networks (specifically, Passive NGN, NGRN).

2.3.3.2 Network Structure

2.3.3.2.1 Geodetic Reference Point Spacing

Geodetic reference point spacing within the NVN should not exceed 6 kilometers.

2.3.3.2.2 Sub-Networks

A subset of geodetic reference points may be designated as a sub-network of the NVN. Geodetic reference points should be selected for inclusion in the sub-network based on common criteria (e.g. point stability) or purpose (e.g. tide gauge monitoring).

Geodetic reference points within the sub-network are not bound by the requirements of [Section 2.3.2.2.1](#) and may be spaced at any interval appropriate under the reason for establishing the sub-network.

Currently, three sub-networks exist within the NVN as per [Table 6](#) below.

Table 6: NVN Sub-Networks (as of March 2024)

Sub-Network	Geodetic Reference Points	Selection Criteria
Fundamental Order	1	JED B Tide Gauge Benchmark
Primary Order	279	Junction Points and Tide Gauge Deformation Monitoring Benchmarks
Secondary Order	3649	Benchmarks

2.3.3.2.3 Other Networks

The active geodetic points that comprise the KSA-CORS Network shall not be considered part of the NVN, unless they are linked by precise leveling and gravity observations.

The tide gauges that comprise the National Tide Gauge Network (NTGN) may be considered part of the NVN provided they meet the requirements set out in [Section 2.3.2.4](#).

The geodetic reference points that comprise other networks (Passive NGN, NGrN) may be considered part of the NVN provided they meet the requirements set out in [Section 2.3.2.4](#).

The structure of the NVN in September 2022 is shown in Figure 2.



Figure 2: National Vertical Network (Source: SANSRS Technical Summary ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#))).

The current structure of the NVN is available at the following website <https://www.geosa.gov.sa/En/Products/Geodesy/Pages/NVN.aspx>.

2.3.3.3 Site Considerations

The passive geodetic benchmarks that comprise the NVN should be established and maintained in accordance with the following guidelines:

In terms of terminology use the same comments in 2.3.2.3. for entire 2.3.3.3.

2.3.3.3.1 Site Location Selection

New Passive NVN reference points must be:

- Installed in solid rock or stable ground such that the geodetic reference point is unlikely to be subject to localized displacement (natural or anthropogenic) or periodic movement (e.g. seasonal movement). If solid rock or stable ground is unavailable the installed geodetic reference point should penetrate the unstable surface soil to the depth of refusal (solid rock or stable ground). Examples of geodetic reference points suitable for use in these scenarios are available in [Annex A](#).
- Installed in a location where the geodetic reference point is unlikely to be disturbed, damaged, removed, or to constitute a hazard.
- Installed in a location that maximizes the utility of the geodetic reference point within the NGN, NVN, and NGrN.
- Installed in a location that provides (and will continue to provide) an optimal GNSS observing environment (see [Section 2.4.1.3](#)).
- Installed in a location that is accessible, thereby allowing for the proper use and maintenance of the geodetic reference point.

2.3.3.3.2 Identification

New Passive NVN reference points must be:

- Permanently and clearly marked with a unique identifier to ensure unambiguous identification. A station identifier should be engraved or stamped on the geodetic reference point, or a durable tag with the identifier firmly attached.
- Accompanied by a marker post or indicator if the geodetic reference point may be difficult to locate.
- Recorded using geotagged digital photos showing the geodetic reference point and its surrounds.
- Recorded on an annotated aerial image or digital recovery sketch that identifies the location of the geodetic reference point in relation to surrounding features.

2.3.3.3.3 Monumentation

New Passive NVN reference points must be:

- Constructed of high-quality, durable, corrosion-resistant materials.
- Constructed and installed according to the relevant design drawings.
- Compliant with any planning, construction, occupational health and safety, or other applicable codes, regulations, or laws that apply in the KSA.

Additional details on materials, designs, and installation procedures can be found in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.3.3.3.4 Maintenance

Routine maintenance of the geodetic reference points and their surrounds is required to ensure that they remain fit for purpose. Routine maintenance, in the form of a physical inspection of the geodetic reference point and surrounds, shall occur:

- Once every five years.
- In response to reports of damaged, destroyed, or missing geodetic reference points.
- In response to geophysical events.
- During re-observation of an existing geodetic reference point.

The purpose of any actions undertaken during routine maintenance shall be to restore the geodetic reference point and its surrounds to a fit-for-purpose state in accordance with these Guidelines.

If a geodetic reference point or its surrounds are unable to be restored to a fit-for-purpose state, a suitable replacement should be installed, subject to the requirements of this section.

2.3.3.4 Realization

The physical height of an NVN reference point must be realized in KSA-VRF14 using an approved height transfer technique, network adjustment, and existing geodetic reference points within the NVN.

- The height transfer and network adjustment techniques utilized must conform with at least the Class 2 guidelines described in .
- The physical height must be derived from at least two existing NVN reference points.
- The physical height must be accompanied by evidence that the accuracy requirements ([Section 2.3.3.5](#)) have been met.

The 3D position of an NVN reference point must be realized within KSA-GRF17 with an accuracy of ≤ 1.0 meters (95% Confidence). When the NVN reference point serves concurrently as a Passive NGN reference point, the 3D position must be realized in accordance with [Section 2.3.2.4](#).

2.3.3.5 Accuracy Requirements

The accuracy requirement for any two geodetic reference points with physical heights H_1 and H_2 connected by a leveling line of d kilometers in length is given by:

$$\sqrt{\sigma_{H_2}^2 + 2\sigma_{H_2H_1} + \sigma_{H_1}^2} \leq 0.002\sqrt{d} \quad (1)$$

Where:

$$\begin{aligned} \sigma_{H_2}^2 &= \text{Variance of } H_2 \text{ (in } m^2) \\ \sigma_{H_2H_1} &= \text{Covariance between } H_2 \text{ and } H_1 \text{ (in } m^2) \\ \sigma_{H_1}^2 &= \text{Variance of } H_1 \text{ (in } m^2) \\ d &= \text{levelling line distance (in kilometers)} \end{aligned}$$

The required variances and covariances must be obtained from the results of a fully constrained least squares network adjustment of the network used to establish H_1 and H_2 .

2.3.3.5.1 Assigning Class

If the requirements of [Section 2.3.3.5](#) are met, the Class of the geodetic reference point is assigned as follows:

Table 7: Assigning Class (NVN) ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#))

Class	Largest Relative Accuracy
0	$\leq 0.0005\sqrt{d}$
1	$\leq 0.001\sqrt{d}$
2	$\leq 0.0013\sqrt{d}$
3	$\leq 0.002\sqrt{d}$

To determine the largest relative accuracy for the geodetic reference point, compute the relative accuracy ([Section 2.3.3.5](#)) between the point and all directly connected points in the network. The largest of these values is the largest relative accuracy value.

2.3.3.6 Monitoring

2.3.3.6.1 Periodic Monitoring

At least every 10 years the KSA-VRF14 physical height of each NVN reference point must be verified by comparing the existing physical height with the physical height determined by GNSS/Leveling (see [Section 2.4.3](#)).

If the difference between the existing physical height and the physical height determined by GNSS/Leveling exceeds the accuracy threshold defined in [Section 2.3.3.5](#) of the physical height difference, then the following actions must be taken:

- The physical height of the geodetic reference point must be re-computed in accordance with [Section 2.3.3.4](#).
- If the difference between the existing and re-computed physical heights is within the propagated accuracy threshold of the physical height difference the existing physical height may be retained or updated at the discretion of the responsible authority.
- If the difference between the existing and re-computed physical heights exceeds the propagated accuracy threshold of the physical height difference the difference must be investigated further. Based on the outcome of the investigation a decision to retain or update the existing physical height must be made.

The geodetic reference point should be removed from the NVN (including any sub-networks) until the discrepancy is resolved.

2.3.3.6.2 Special Events

A special event is defined as any occurrence that could reasonably be considered to impact the physical height of an NVN reference point. Examples of such events include:

- Seismic or other geophysical events.
- Damage to the geodetic reference point or supporting infrastructure.
- Construction in the vicinity of the geodetic reference point.
- Groundwater, oil or gas extraction, flooding, or prolonged drought.

The impact of the event on the physical height of the NVN reference point should be ascertained through an analysis of the physical height of the NVN reference point before and after the event, based on the requirements in [Section 2.3.3.6.1](#).

If the analysis indicates a significant impact on the physical height of the NVN reference point, then the physical height of the NVN reference point must be re-computed in accordance with [Section 2.3.3.4](#).

2.3.3.7 Publication

The physical height, 3D positions, accuracy, and relevant metadata for all geodetic reference points within the NVN must be made available to the general public via a findable and accessible medium.

The recommended medium is an online website or portal.

2.3.4 National Gravity Network

2.3.4.1 Definition

The National Gravity Network (NGrN) is a network of passive gravity points that provide a gravity datum throughout the KSA. The primary purpose of the NGrN is as a high-quality reference frame for gravity surveys (land, marine, airborne) conducted within and around the KSA. In addition, the NGrN is a fundamental data source for the determination of a National Vertical Reference Network (NVRF) (e.g. KSA-VRF14) and the computation of regional geoid models (e.g. KSA-GEOD21).

2.3.4.2 Network Structure

2.3.4.2.1 Geodetic Reference Point Spacing

The density of geodetic reference points designed for observing absolute gravity needs to be at least one point per 90,000 km². These points should be homogeneously distributed throughout the KSA.

The spacing of geodetic reference points designed for observing relative gravity shall not exceed 6 kilometers.

2.3.4.2.2 Sub-Networks

A subset of geodetic reference points may be designated as a sub-network of the NGrN. Geodetic reference points should be selected for inclusion in the sub-network on the basis of common criteria (e.g. absolute gravity observations) or purpose (e.g. gravimeter calibration).

Geodetic reference points within the sub-network are not bound by the requirements of [Section 2.3.4.2.1](#) and may be spaced at an interval appropriate to the purpose of the sub-network.

Currently, three sub-networks exist within the NGrN (Table 8).

Table 8: NGrN Sub-Networks (as of March 2024)

Sub-Network	Geodetic Reference Points	Selection Criteria
Fundamental Order	106	Gravity Base Network (GBN) and Gravity Calibration Baseline (GCB). Absolute gravimetry of at least Class 1.
Primary Order	245246	Primary Gravity Network (PGRN). Homogeneous national distribution. Relative gravimetry of at least Class 2.
Secondary Order	34693468	Secondary Gravity Network (SGN) Co-location with NVN, Passive NGN. Relative gravimetry of Class 2.

2.3.4.2.3 Other Networks

The active geodetic points that comprise the KSA-CORS Network shall not be considered part of the NGrN.

The geodetic reference points that comprise other networks (Passive NGN, NVN) may be considered part of the NGrN provided they meet the requirements set out in [Sections 2.3.2.3.3](#) and [2.3.3.3.3](#).

2.3.4.2.4 Status

As of September 2022, Figure 3 depicts the structure of the NGrN.

The current structure of the NGrN is available at the following website <https://www.geosa.gov.sa/En/Products/Geodesy/Pages/NGN.aspx>.



Figure 3: National Gravity Network (Source: SANSRS Technical Summary ([General Authority for Survey and Geospatial Information, GEOSA, 2022](#))).

2.3.4.3 Site Considerations

The following guidelines apply to geodetic reference points whose primary purpose is to support absolute gravimetry.

These guidelines may apply (in part) to geodetic reference points where the primary purpose is relative gravimetry.

For guidelines related to geodetic reference points where gravity observations are of secondary importance (e.g. NGN, NVN points) see and .

2.3.4.3.1 Site Location Selection

New NGrN points for the observation of absolute gravity must be:

- Installed in a location that is geologically and geo-physically stable, with minimal microseismic activity, and a low probability of exposure to vibration (e.g. heavy traffic, trains).
- Installed in a location that is secured from the general public (e.g. government offices).
- Installed indoors (primary reference point) with a secondary (eccentric) reference point outdoors, within 20 meters of the primary point.
- Installed in a location where the geodetic reference point is unlikely to be disturbed, damaged, removed, or to constitute a hazard.
- Installed in a location that is accessible, thereby allowing for the proper use and maintenance of the geodetic reference point.

2.3.4.3.2 Identification

New NGrN points for the observation of absolute gravity must be:

- Permanently and clearly marked with a unique identifier to ensure unambiguous identification. A station identifier should be engraved or stamped on the geodetic reference point, or a durable tag with the identifier firmly attached.
- Accompanied by a marker post or indicator if the geodetic reference point may be difficult to locate.
- Recorded using geotagged digital photos showing the geodetic reference point and its surrounds.
- Recorded on an annotated aerial image or digital recovery sketch that identifies the location of the geodetic reference point in relation to surrounding features.

2.3.4.3.3 Monumentation

New NGrN points for the observation of absolute gravity must be:

- Constructed of high-quality, durable, corrosion-resistant materials.
- Constructed and installed according to the relevant design drawings.
- Compliant with any planning, construction, occupational health and safety, or other applicable codes, regulations, or laws that apply in the KSA.

Additional details on materials, designs, and installation procedures can be found in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.3.4.3.4 Maintenance

Routine maintenance of the geodetic reference points and their surrounds is required to ensure that they remain fit for purpose. Routine maintenance, in the form of a physical inspection of the geodetic reference point and surrounds, shall occur:

- Once every five years.
- In response to reports of damaged, destroyed, or missing geodetic reference points.
- In response to geophysical events
- During re-observation of an existing geodetic reference point.

The purpose of any actions undertaken during routine maintenance shall be to restore the geodetic reference point and its surrounds to a fit-for-purpose state in accordance with these Guidelines.

If a geodetic reference point or its surrounds are unable to be restored to a fit-for-purpose state, a suitable replacement should be installed, subject to the requirements of this section.

2.3.4.4 Realization

Gravity values at NGrN points must be realized via absolute gravimetry or relative gravimetry.

When realizing gravity values via absolute gravimetry:

- Survey techniques of at least Class 1 are to be utilized (see [Section 2.4.4.1](#)).
- A minimum of two realizations, five years apart, that produce equivalent gravity values (within the accuracy requirements in [Section 2.4.4.1.1](#)) must be obtained before the geodetic reference point is considered stable and included in the NGrN.

- The gravity values must be accompanied by evidence that the accuracy requirements ([Section 2.3.4.5](#)) have been met.

When realizing gravity values via relative gravimetry:

- Survey techniques of at least Class 2 are to be utilized (see [Section 2.4.4.2](#)).
- The gravity value must be determined relative to at least two other NGrN reference points.
- The gravity values must be accompanied by evidence that the accuracy requirements ([Section 2.3.4.5](#)) have been met.

The physical height of an NGrN reference point must be realized in KSA-VRF14 in accordance with [Section 2.3.3.4](#).

The 3D position of an NGrN reference point must be realized within KSA-GRF17 with an accuracy of ≤ 1.0 meters (95% Confidence). When the NGrN reference point serves concurrently as a Passive NGN reference point, the 3D position must be realized in accordance with [Section 2.3.2.4](#).

2.3.4.5 Accuracy Requirements

Gravity values, realized according to [Section 2.3.4.4](#), must have an accuracy of at least 100 μGal (95% Confidence).

2.3.4.5.1 Assigning Class

If the requirements of [Section 2.3.4.5](#) are met, the Class of the geodetic reference point is assigned as follows:

Table 9: Assigning Class (NGrN) ([General Authority for Survey and Geospatial Information, GEOISA, 2024](#))

Class	Accuracy (95%)
0	40 μGal
1	40 μGal
2	100 μGal
3	>100 μGal

2.3.4.6 Monitoring

2.3.4.6.1 Periodic Monitoring

Periodic monitoring is only required for geodetic reference points where absolute gravimetry was the survey technique used to realize the gravity value.

At least every ten years the gravity value of the relevant NGrN point must be verified by re-observing and re-computing the gravity value via absolute gravimetry in accordance with [Section 2.4.4.1](#).

If the difference between the existing value of absolute gravity and the re-observed value of absolute gravity exceeds the propagated accuracy threshold of the absolute gravity difference, the following actions must be taken:

- In the event that the difference between the existing value of absolute gravity and the re-observed value of absolute gravity exceeds the propagated accuracy threshold of the absolute gravity difference, the discrepancy must be investigated (including additional absolute or relative gravimetry surveys, if appropriate) and the discrepancy resolved.

The geodetic reference point should be removed from the NGrN (including any sub-networks) until such time as the discrepancy is resolved.

2.3.4.6.2 Special Events

A special event is defined as any occurrence that could reasonably be considered to impact the value of absolute gravity or the physical height of an NGrN reference point. Examples of such events include:

- Seismic or other geophysical events.
- Damage to the geodetic reference point or supporting infrastructure.
- Construction in the vicinity of the geodetic reference point.
- Groundwater, oil or gas extraction, flooding, or prolonged drought.

The impact of the event on the value of absolute gravity and the physical height of the NGrN reference point needs to be ascertained through an analysis of the absolute gravity and physical height before and after the event, based on the requirements in [Section 2.4.4.1.1](#).

If the analysis indicates a significant impact on the value of absolute gravity and/or the physical height of the NGrN reference point then the value of absolute gravity and the physical height of the NGrN reference point must be re-computed in accordance with [Section 2.4.4.1.1](#).

2.3.4.7 Publication

The gravity value, physical height, 3D positions, accuracy, and relevant metadata for all geodetic reference points within the NGrN must be made available to the general public via a findable and accessible medium.

The recommended medium is an online website or portal.

2.4 Geodetic Surveys

2.4.1 GNSS Surveys

2.4.1.1 Introduction

GNSS surveys can vary in accuracy from several meters to several millimeters depending on the type of equipment and observation technique used.

There are four fundamental GNSS techniques:

- Single Point Positioning (SPP),
- Precise Point Positioning (PPP),
- Differential GNSS (DGNSS),
- Relative positioning (static baseline).

GNSS Datum Control Surveys and General-Purpose Control Surveys require the highest levels of accuracy to be achieved. This Guideline therefore covers only static baseline and PPP techniques, while the SPP and DGNSS techniques are not considered. The static baseline approach will be treated under the sub-headings of Static and Fast Static.

2.4.1.2 Accuracy Aspects

Tables Table 10 to Table 12 list the recommended GNSS observation techniques for Static, Fast Static, and PPP surveys to achieve the nominated levels of accuracy at 95% confidence.

2.4.1.2.1 Static GNSS Survey

Static GNSS surveying typically requires a minimum of several hours to 24 hours of stationary observation time, depending on the desired accuracy.

Table 10: Static GNSS Survey Parameters

Technique	Static
Session Length	6-24 hours
Observation Time Interval	30 seconds
Baseline Length	<2000 km
Accuracy (95% confidence)	< 10 mm for horizontal position, < 20 mm for ellipsoidal height
Class	Class 0, 1, 2

2.4.1.2.2 Fast Static GNSS Survey

The Fast Static technique is similar to Static except that, over shorter baselines, (e.g. less than 20 km) it is possible to observe for considerably less time and still achieve similar accuracies.

Table 11: Fast Static GNSS Survey Parameters

Technique	Fast Static
Session Length	1-6 hours
Observation Time Interval	10 seconds
Baseline Length	< 100 km
Accuracy (95% confidence)	< 30 mm for horizontal position, < 50 mm for ellipsoidal height
Class	Class 2, 3

2.4.1.2.3 Precise Point Positioning (PPP)

PPP in effect is also a static survey technique, however, only a single receiver and antenna are required. The code and carrier phase observations are processed using externally provided GNSS orbit and clock corrections, either using software or an online PPP processing service. Depending on the observed time interval, PPP can also match, or at least approach, the accuracy of a static survey.

Table 12: PPP GNSS Survey Parameters

Technique	PPP
Session Length	6-24 hours
Observation Time Interval	30 seconds
Baseline Length	N/A
Accuracy (95% confidence)	< 20 mm for horizontal Position, < 30 mm for ellipsoidal height
Class	Class 2, 3

2.4.1.3 GNSS Survey Observations

GNSS observations for Datum Control Surveys and General-Purpose Control Surveys require careful planning, equipment considerations, and field procedures to be followed to achieve the required accuracies.

2.4.1.3.1 GNSS Survey Planning

The following factors must be considered when planning a GNSS survey:

- Project scope and objectives,
- Equipment selection,
- Appropriate control points,
- Survey plan (e.g. survey technique, occupation times, etc.),
- Quality control checks,
- Documentation of survey procedures and results.

More detailed information can be found in the GEOISA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOISA, 2024](#)).

2.4.1.3.2 GNSS Survey Methodology

The methodology to be used in a GNSS survey will be dictated by the accuracy requirements of the project. These will determine the choice of technique, equipment, observation time, baseline length, data collection rate, and processing methodology.

The following equipment guidelines may be used for Static and PPP surveys in KSA ():

Table 14: GNSS Equipment Guidelines

Class	Class 0	Class 1	Class 2	Class 3
Verify GNSS equipment annually	Yes	Yes	Yes	Yes
IGS Absolute Antenna models applied	Yes	Yes	Yes	Yes
Multi-constellation GNSS capability	Yes	Yes	Optional	Optional
Minimum signal frequency tracking capability	Dual	Dual	Dual	Dual
Minimum elevation angle	0°	0°	0°	0°
GNSS antenna type	Choke ring	Choke ring or survey grade	Survey grade	Survey grade

2.4.1.4 Processing and Adjustment

2.4.1.4.1 GNSS Survey Methodology

GNSS processing needs to be done using specialist software or an online service. The post-processing technique will depend on the type of survey carried out – static baseline or PPP.

In the case of a static baseline, the typical steps in the processing include:

- Importing data from two or more receivers,
- Identifying reference and rover receivers and fixing the coordinates of the reference,
- Pre-processing (e.g. cycle slip detection, outlier rejection, etc.),
- Baseline formation,
- Ambiguity resolution,
- Position computation,
- Achieved accuracy estimation,
- Quality control checks.

In the case of PPP, the typical process is as follows:

- Importing data from a single receiver (rover),
- Importing orbit and clock corrections and other biases,
- Pre-processing (e.g. application of corrections, cycle slip detection, outlier rejection, etc.),
- Ambiguity resolution (optional),
- Position computation,
- Achieved accuracy estimation,
- Quality control checks.

There are several online GNSS processing services available based on both static baseline processing and PPP techniques. If using such a service, the user typically only needs to submit a data file in a standard format such as Receiver Independent Exchange Format (RINEX), as well as select some basic settings, and the results will be returned via email when the processing is complete.

It should be noted that when using an online service, the user has limited to no control over the settings of the positioning computation process, and as such these services need to be used with caution. In order to have full control of the positioning computation, scientific or commercial GNSS processing software must be used.

The following procedures need to be applied for Static and PPP data processing when using GNSS processing software ([New South Wales, NSW Spatial Services, 2021](#)):

Table 13: GNSS Observation Procedures

Class	Class 0	Class 1	Class 2	Class 3
GNSS processing software	Scientific	Commercial	Commercial	Commercial
Final IGS Satellite Ephemerides	Yes	Optional	Optional	Optional
Ionospheric model applied	Higher Order Ionospheric (HOI)	Standard	Standard	Standard
Tropospheric model applied	Zenith Tropospheric Delay (ZTD)	Standard	Standard	Standard
Stochastic model applied	Rigorous	Non-rigorous	Non-rigorous	Non-rigorous
Achieve ambiguity resolution	Yes	Yes	Yes	Yes

2.4.1.4.2 GNSS Network Adjustment

After the GNSS processing is complete, a network adjustment needs to be done to integrate the newly acquired position data with the existing control network. Network adjustment for control surveys is typically done using the least squares method.

The inputs to the GNSS network adjustment include:

- GNSS baseline components.
- Variance-covariance matrices for (and sometimes between) each baseline.

The outputs of the network adjustment include:

- 3D position coordinates.
- 3D accuracy estimates.

2.4.1.5 Submission Guidelines

The submission documents for GNSS surveys to GEOSA need to include:

- Survey plan,
- Equipment and software list,
- Control points report,
- GNSS data in RINEX format,
- GNSS metadata,
- GNSS data processing and network adjustment report.

2.4.2 Precise Geodetic Leveling Surveys

2.4.2.1 Introduction

For this guideline, geodetic leveling refers to the method of observing a height difference between two points using a level and staff. This method is sometimes referred to as differential leveling or geometric leveling.

2.4.2.2 Accuracy Aspects

KSA guidelines for geodetic leveling have been developed based on the NGS standards that were published via the Federal Geodetic Control Committee () taking into account some regional requirements. The NVN has been divided into four classes with respect to the elevation difference accuracy (). The associated requirements for the elevation difference accuracy and network geometry are shown in Table 16:

Table 14: KSA Vertical Network Accuracy Classification.

Parameters	Class 0	Class 1	Class 2	Class 3
Maximum elevation difference accuracy (mm)	$0.5\sqrt{d}$	$1.0\sqrt{d}$	$1.3\sqrt{d}$	$2.0\sqrt{d}$
Maximum length of leveling line (km)	As needed	As needed	50, double run 25, single run	25, double run 10, single run
Spacing between benchmarks (km)	6	6	6	6
Spacing between temporary benchmarks (km)	3	3	3	3

New geodetic leveling needs to be connected to the existing NVN. Connections need to be made at the beginning and end of the new leveling line. The reference network has to be of the same Class or better than the intended class of the new survey.

If geodetic leveling of Class 0 is being carried out, connections need to be made to at least six existing benchmarks. For other classes, this number can be reduced to four. In addition, if a new leveling pass an existing benchmark at a distance of not more than 3 km, the new leveling needs to be connected to the existing benchmark. If a new leveling line runs parallel to an existing leveling line, a connection survey needs to be made according to the guidelines provided in Table 17.

Table 15: Requirements for Connection Surveys to the Existing Leveling Network

Distance to existing network [km]	Maximum spacing of connection survey [km]
0.5 or less	5
0.5 – 2.0	10
2.0 – 3.0	20

2.4.2.3 Leveling Observations

Before commencing a leveling survey, reconnaissance and site selection needs to be carried out. The reconnaissance activities need to follow the process described in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

Precise geodetic leveling needs to be done by section, where each section comprises a series of consecutive instrument setups between pairs of adjacent points. Depending on the required survey class, the leveling must be carried out using one of the following techniques:

- Single-Run, Double Simulations (SRDS) – a level line composed of two single-run lines over the same route, both in the same direction, but using different turning points.
- Double-Run (DR) – a level line in which the measurements are made from the starting point to the endpoint and then back again.
- Single-Run (SR) – a level line established by measuring height differences in one direction only.
- Spur (SP) – a level line that is connected to a leveling network but is neither part of the principal leveling network nor part of a loop.

The requirements for precise leveling in KSA have been developed based on NGS standards ([Federal Geodetic Control Committee, FGCC, 1984](#)) and are provided in Table 16:

Table 16: Requirements for Precise Leveling Observations

Parameters	Class 0	Class 1	Class 2	Class 3
Sections running	SRDS or DR or SP	SRDS or DR or SP	SRDS or DR	SRDS or DR or SR ¹
Difference between forward and backward sight lengths should never exceed:				
per setup (m)	2	5	10	10
per section (m)	4	10	10	10
Maximum length of sight (m)	50	60	70	90
Minimum ground clearance of line of sight (m)	0.5	0.5	0.5	0.5
Even the number of setups when not using leveling rods with detailed calibration	Yes	Yes	Yes	–
Observation sequence at each leveling setup	BFFB ²	BFFB ²	BFFB ²	BFFB ²
Maximum allowed elevation difference for one setup (mm)	0.30	0.30	0.30	0.30
Minimum number of multiple readings for one measurement ³	3	3	3	3
Determine the temperature gradient for the vertical range of the line of sight at each setup	Yes	Yes	–	–
Resolution of temperature readings	0.1°C	0.1°C		
Maximum section misclosure (mm) (<i>D</i> – is the shortest length of section in km)	$3\sqrt{D}$	$6\sqrt{D}$	$8\sqrt{D}$	$12\sqrt{D}$
Maximum loop misclosure (mm) (<i>E</i> – is a perimeter of a loop in km)	$4\sqrt{E}$	$6\sqrt{E}$	$8\sqrt{E}$	$12\sqrt{E}$

¹ – If the line between the network and control point doesn't exceed 10 km.

² – Backward-Forward-Forward-Backward (BFFB).

³ – If the standard deviation from multiple readings exceeds 0.1 mm, the measurements should be continued until it is not less than 0.1 mm.

In addition to Table 18, the following guidelines have to be considered during geodetic leveling:

- For minimization of the refraction effects, the height of the instrument needs to be as high as possible.
- For minimization of the collimation, earth curvature, and refraction effects, backsight and foresight distances must be kept approximately equal.
- During daylight, an umbrella must be used to protect the instrument from the direct bright sunlight.
- A turning plate must be used during the leveling process. In soft ground, a turning pin with a driving cap can be utilized instead.

2.4.2.4 Instrumentation and calibration

The general requirements for leveling instruments and rods are given in Table 17.

Table 17: General Requirements for Leveling Instruments and Rods

Parameters	Class 0	Class 1	Class 2	Class 3
Leveling instrument: Minimum repeatability of the line of sight	0.40"	0.40"	0.80"	1.00"
Leveling rods: Construction	Invar, single scale			Wood or metal
Instrument and rods resolution: Least count (mm)	0.01	0.01	0.10	0.10

Equipment checks and calibration procedures including collimation checks and Quality Control (QC) procedures need to be done according to the methods specified in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

Leveling instrument collimation checks, and rods calibrations should be performed according to the requirements listed in Table 18.

Table 18: Requirements for Leveling Instrument Collimation Check and Rods Calibrations

Parameters	Class 0	Class 1	Class 2	Class 3
Leveling instrument				
Maximum collimation error, single line of sight (mm/m)	0.05	0.05	0.05	0.10
Maximum collimation error, reversible compensator-type instruments, mean of two lines of sight (mm/m)	0.02	0.02	0.02	0.04
Time interval between collimation error determinations not longer than (days)	1	1	7	7
Maximum angular difference between two lines of sight	40"	40"	40"	60"
Leveling Rod				
Minimum scale calibration standard	Manufacturer			
Time interval between scale calibrations (year)	3	-	-	-

2.4.2.5 Processing and Adjustment

2.4.2.5.1 Precise Leveling Processing

The quality control of the leveling data processing should be performed following the requirements listed in Table 19 below.

Table 19: Requirements for the Processing of Precise Leveling Observations

Parameters	Class 0	Class 1	Class 2	Class 3
Section misclosures (backward and forward)				
Maximum algebraic sum of all corrected section misclosures of leveling line (mm): (D – is the shortest one-way length of the leveling line in km)	$3\sqrt{D}$	$6\sqrt{D}$	$8\sqrt{D}$	$12\sqrt{D}$
Maximum section misclosure (mm): (E – is the shortest one-way length of the section in km)	$3\sqrt{E}$	$6\sqrt{E}$	$8\sqrt{E}$	$12\sqrt{E}$
Loop misclosures				
Maximum algebraic sum of all corrected misclosures:	$4\sqrt{F}$	$6\sqrt{F}$	$8\sqrt{F}$	$12\sqrt{F}$
Maximum loop misclosure: (F – is the length of a loop in km)	$4\sqrt{F}$	$6\sqrt{F}$	$8\sqrt{F}$	$12\sqrt{F}$

The entire process of processing the geodetic leveling observations consists of the following steps:

- Leveling data correction,
- Sections, lines, and loop closures,
- Systematic error analysis.

Leveling data corrections include the following:

- Collimation correction,
- Rod scale correction,
- Rod temperature correction,
- Earth's curvature correction,
- Astronomic correction,
- Refraction correction,
- Gravity corrections.

The details of the procedures on how to apply the leveling data corrections as well as carry out the closures and the systematic error analysis are found in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.2.5.2 Adjustment

The adjustment of precise leveling networks is performed utilizing least squares. During the adjustment process, corrections are applied to each leveling line taking into account precision, usually based on length, employed equipment, and survey methodology to estimate the final levels of all points used in the survey and the accuracy of those heights.

The procedure of applying the least squares mathematical mode to the leveling adjustment is described in the General Authority for Survey and Geospatial Information (GEOSA) Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.2.6 Submission Guidelines

The submission documents to GEOSA for precise leveling surveys include the following:

- QA/QC Plan,
- Reconnaissance report,
- Survey plan,
- Monumentation report and Benchmark (BM) description cards,
- Final report.

Details on each of these deliverables are described in the GEOISA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOISA, 2024](#)).

2.4.3 GNSS/Leveling Surveys

2.4.3.1 Introduction

GNSS/leveling is a height determination method based on static GNSS observations and a geoid model.

As shown in [Section 2.4.1](#), GNSS can observe heights to an accuracy of <20mm using Static methods. Whilst conventional geodetic leveling can be used to observe heights to millimeter-level accuracy over short distances, this error increases with distance, whereas GNSS errors remain largely the same over distances of up to a few tens of kilometers. On a medium scale, both techniques achieve comparable accuracy.

GNSS can only provide ellipsoidal height differences (h), so in order to compute orthometric heights (H), a geoid ellipsoid separation (N) must be applied.

In KSA, in order to perform GNSS/leveling, the following conditions must be met:

- GNSS observations need to be taken using the Static method.
- GNSS observations need to be processed to yield KSA-GRF17 ellipsoidal height differences.
- KSA-GEOID21 needs to be used as the geoid model.

2.4.3.2 Accuracy Aspects

The accuracy of a GNSS/leveling survey depends on:

- Accuracy of the Static GNSS survey and resultant ellipsoidal height difference.
- (Relative) accuracy of the gravimetric geoid model.

The first factor can be derived from the network adjustment statistics of the GNSS survey. The second is not as easy to determine, as combined hybrid geoid models such as KSA-GEOID21 are affected by several compounding errors. Geoid model accuracy varies depending on geographic location, quality, coverage, and density of available gravity data, terrain variations, and the regularity of the geoid.

KSA-GEOID21 is stated to have an absolute precision of 15 mm along leveling lines and 25 mm between leveling lines according to the SANSRS Technical Summary ([General Authority for Survey and Geospatial Information, GEOISA, 2022](#)).

The resultant orthometric height accuracy may be computed using the propagation of variance formulae. As an example, if the ellipsoid height accuracy resulting from a GNSS survey is ± 15 mm and the accuracy of KSA-GEOID21 in the area is ± 25 mm, the resultant accuracy would be ± 29 mm as shown below:

$$29 = \sqrt{15^2 + 25^2}$$

It was shown by [Brown et al., 2018](#) that GNSS/leveling is capable of achieving equivalent or better than Class 3 geodetic leveling beyond distances beyond 3 km using the AusGeoid2020 geoid model in Australia, which has comparable accuracy characteristics to KSA-GEOID21.

2.4.3.3 Observations

GNSS/leveling consists of GNSS observations and the application of the geoid model. In that respect, the GNSS observations need to be acquired using the process described in [Section 2.4.1.3](#).

2.4.3.4 Processing and Adjustment

GNSS data processing and adjustment must be carried out as described in [Section 2.4.1.3](#) and [2.4.1.4](#) respectively to compute ellipsoidal heights of each point in the network along with their associated accuracies.

As a final step, geoid undulations (N) from KSA-GEOD21 must be applied to the ellipsoidal heights (H) to convert them to orthometric heights (h) according to the following formula:

$$H = h - N \quad (2)$$

2.4.3.5 Submission Guidelines

The submission documents to GEOSA for GNSS/leveling surveys need to include:

- Survey plan,
- Equipment and software list,
- Control points report,
- GNSS data in RINEX format,
- GNSS metadata,
- Data processing and network adjustment report,
- Orthometric heights computation report.

2.4.4 Gravimetric Surveys

Gravimetric surveys can be land, ship, air, or satellite-based, depending on the platform used to carry the gravity sensor. This guideline provides guidance for land-based gravimetric surveys only.

Land-based gravimetric surveys can be further subdivided into two categories:

- Absolute gravimetric survey - measures absolute gravity based on the free fall of a body in a vacuum, using lasers and optical interferometry, to obtain accuracies typically better than 0.01 mGal.
- Relative gravimetric survey - measures the difference in the magnitude of gravity from point to point, utilizing the elongation of a spring which supports the displacement of the proof mass by the influence of the gravity force.

The classification of gravity control networks in KSA is based on the NGS standards ([Federal Geodetic Control Committee, FGCC, 1984](#)) as specified in Table 9.

Class 0 networks need to be observed twice a year for five years to ensure long-term gravity changes do not exceed 20 μ Gal. If the gravity value of a Class 0 point exceeds this criterion, the point needs to be re-classified as Class 1, until the aforementioned requirement is satisfied ([Federal Geodetic Control Committee, FGCC, 1984](#)).

2.4.4.1 Absolute gravity survey

Since absolute gravity observations are discrete and spatially uncorrelated, there are no specific requirements regarding network station geometry. The main objective is achieving homogeneous distribution, ensuring the time of travel between neighboring sites is not more than 12 hours. In the case of KSA, the approximate distance between points should not exceed 300 km, thereby ensuring relative gravimetry with sufficient absolute gravity reference stations.

2.4.4.1.1 Accuracy Aspects

Absolute gravity surveys are typically performed to establish gravity networks of Class 0 and Class 1.

Requirements for absolute gravity observations are listed in Table 20.

Table 20: KSA Requirements for Absolute Gravity Observations

Parameters	Class 0	Class 1
Absolute gravity measurements		
Standard deviation of each accepted measurement set not to exceed (μGal)	20	20
Minimum number of observations/sets?	10	5
Maximum difference of a measurement set from the mean of all measurements (μGal)	12	12
Barometric pressure standard error (mbar)	4	4
Vertical gravity gradient measurements		
Standard deviation of measurement of vertical gravity gradient at time of observation ($\mu\text{Gal}/\text{m}$)	5	5
Standard deviation of height of instrument above point (mm)	1	1

2.4.4.1.2 Absolute gravity observations

Absolute gravity observations need to be collected following the steps described below. Detailed procedures for each step can be found in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.4.1.2.1 Absolute Gravity reconnaissance and site selection

Each absolute gravity point needs to include one center point (inside a building) and one ex-center point (outdoors within 20 m of the center point). The guidelines for absolute gravity site selection are:

1. The site needs to be easily accessible from existing roads without being affected by local traffic.
2. Driving time between absolute gravity sites needs to be as short as possible.
3. The mark needs to be embedded in a stable concrete pad (pillar). The pad needs to be located on a stable foundation.
4. The pad needs to be suitable for both relative and absolute gravity measurements.
5. Station location needs to be low noise and low micro-seismicity by avoiding traffic, industry, or other man-made activities. It must also be located away from unstable ground and areas of tectonic activity.
6. Concrete pads must avoid electromagnetic interference caused by high-voltage cables.
7. Absolute gravity sites need to be recoverable by adding an ex-center pad with a known absolute gravity value having the same accuracy as the center pad.

2.4.4.1.2.2 Monumentation of absolute gravity control points

The geodetic reference points need to be designed as per the guidelines given in Figure 4 below.

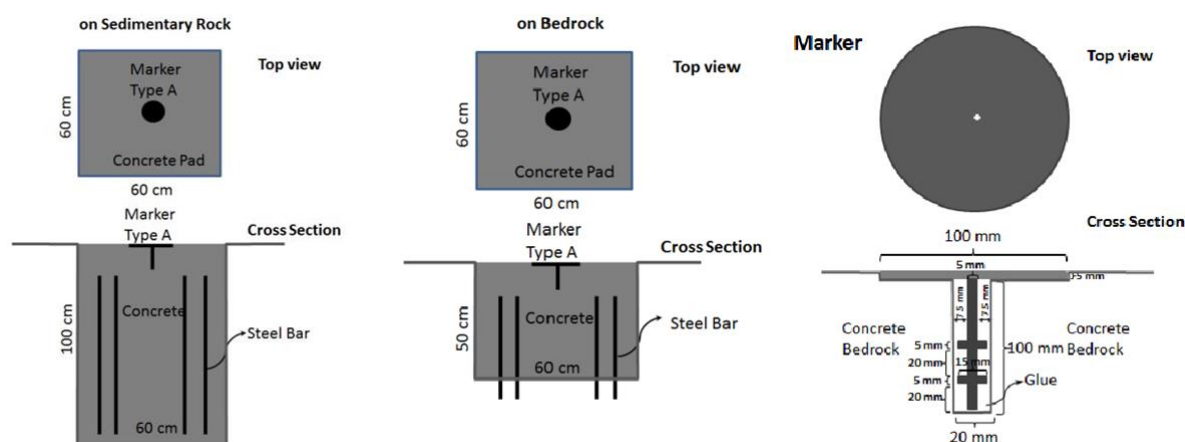


Figure 4: Concrete Pad and Marker for Absolute Gravity Surveys (Source: GEOSA Geodetic Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#))).

The aluminum survey marker needs to be installed on the concrete pad. For a better coupling of the marker to the concrete, two perpendicular steel needles need to be added to the marker as shown in Figure 5.



Figure 5: Survey Marker for Absolute Gravity Station (Source: GEOSA Geodetic Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#))).

2.4.4.1.2.3 Absolute Gravity Instrumentation and Calibration

There are two types of absolute gravimeters, one for permanent observations in a lab and one for field measurements. Before use, calibration of the gravimeter needs to be performed following manufacturer guidelines. Calibration needs to be done at stable sites and the difference between readings cannot exceed 5 μGal , otherwise, manufacturer service and maintenance will be required.

Extensive details on the instrumentation and calibration procedures are provided in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.4.1.2.4 Absolute gravity Observation Procedure

Procedures for both absolute gravity observations and vertical gravity gradient observations are provided below.

For absolute gravity observations absolute gravimeter(s) need to be used at both the center and ex-center stations. If two absolute gravimeters are used, the absolute gravity measurements need to be compared at each station to ensure the differences between the gravity values obtained are less than 7 μGal from the average.

The requirements for absolute gravity observations are as follows:

- Minimum number of time-distance measurements per drop: 200.
- Minimum number of drops per measurement set: 1200.
- Minimum number of measurement sets: 10.
- Approximate duration of observations of evenly spaced sets: 30 – 60 minutes.
- Repeatability for sets is site dependent: 5 μGal .

Vertical gravity gradient observations need to be performed by relative gravimeter(s) in order to observe the gravity difference between the land surface and the height of the absolute gravimeter. Gravity is measured by placing a relative gravimeter at three different levels (heights) over the mounted gravity point utilizing a special tripod.

Before the observations start, each relative gravimeter, after arrival at the observation site, needs to be left undisturbed for a stabilization period of 20-30 minutes. Observations should be performed in a loop sequence, considering each level as an “observation station”:

L1>>L2>>L3 >> L1>>L2>>L3 >> L1>>L2>>L3 >> L1>>L2>>L3 >> L1>>L2>>L3 >> L1

Each set comprises 16 observations: 6 at Level 1 (L1); 5 at Level 2 (L2); and 5 at Level 3 (L3) epochs, with each observation being made up of 5 acceptable readings within 60 seconds. The observation procedure should be as follows:

- Set up the gravimeter at the required level.
- Measure the height of the gravimeter.
- Allow one minute for the gravimeter to stabilize.
- Start 60-second readings.
- Compute the mean of the five readings (epoch mean).
- Compute differences of each reading from the epoch mean.

Check the differences are all less than 2 μGal , if not repeat the measurement at this level.

2.4.4.1.2.5 Absolute gravity data processing

The processing of the absolute gravity survey involves the computation of vertical gravity gradients and the transfer of observed absolute gravity data to the ground.

The computation of vertical gravity gradients for each observed point needs to be done by fitting the observed values using the least squares method, which results in linear and non-linear gravity gradients, as per the following formulas:

Linear gravity gradient:

$$g(h) = a \cdot h + b \quad (3)$$

Non-linear gravity gradient:

$$g(h) = a \cdot h^2 + b \cdot h + c \quad (4)$$

where h is height and a, b and c are fitting coefficients.

2.4.4.1.2.6 Absolute gravity adjustment

Since the absolute gravity observations are performed on each site independently, traditional least squares adjustment procedures inherent for other geodetic surveys, do not apply.

The following corrections need to be applied to the absolute gravity data:

- Earth tides,
- Atmospheric pressure,
- Polar motion,
- Reference X_0 ¹,
- Height,
- Self-attraction,
- Diffraction,
- Tilt.

The description of these corrections is provided in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.4.1.2.7 Absolute Gravity Publication / Submission

The submission requirements to the GEOSA for absolute gravity deliverables include:

- QA/QC plan,
- Reconnaissance report,
- Survey Plan,
- Final report.

Details of each of the deliverables are described in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.4.2 Relative gravity survey

Relative gravity surveys are performed for the purpose of densification of gravity networks established using absolute gravity observations. Relative gravimeters measure gravity between stations. If one station is provided with an absolute gravity value, the gravity at an unknown station can be determined.

2.4.4.2.1 Relative gravity observations

Relative gravity measurements of Class 0 and 1 are performed for the purpose of densification of the network of absolute gravity stations. New stations should be located at intervals of 300 km and be as close as possible to NVN benchmarks.

The purpose of Class 2 measurements is the further densification of Class 0 and Class 1 gravity networks. Class 2 stations need to be located at about 60 km and coincide with NVN benchmarks.

The purpose of Class 3 gravity measurements is to provide gravity control for local gravity surveys for various applications such as geophysical exploration.

¹ This correction refers to the specific features of instrument and represent the shift between point where gravity value is determined and the reference point. In order to correct gravity, reduce gravity to a reference point, the distance to the start point (X_0) should be multiplied by the gravity gradient determined at the site.

New relative gravity survey requires at least two initial reference points of the equivalent or higher class to ensure the accuracy of the new point, and the validity of the existing points, and to check instrument calibration.

The guidelines for relative gravity observations of different classes are based on the NGS standards () as shown in Table 23.

Table 23: Guidelines for Relative Gravity Observations

Parameters	Class 0	Class 1	Class 2	Class 3
Minimum number of instruments used in the survey	3	3	2	2
Allowable loop sequence	a	a	a, b	a, b, c
Minimum number of readings at each observation/instrument station	10	10	10	10
Minimum duration of time series of readings (minutes)	15	15	15	15
Maximum Standard Deviation (STD) of consecutive readings (μGal)	2	2	5	5
Monitor external temperature and air pressure	Yes	Yes	Yes	Yes
Standard deviation of temperature measurements ($^{\circ}\text{C}$)	0.1	0.1	0.1	0.1
Standard deviation of air pressure measurement (mbar)	1	1	1	1
Standard deviation of height of instrument above point (mm)	1	1	1	1

2.4.4.2.2 Relative gravity observations

Acquisition of relative gravity observations needs to follow the steps described below Detailed procedures for each step can be found in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.4.2.2.1 Relative gravity reconnaissance and site selection

General requirements for reconnaissance and site selection for relative gravity stations are similar to those applying to absolute gravity stations with the following additions:

- Class 0 and Class 1 need to be located along the roads as much as possible to coincide with leveling lines at distances of not more than 300 km from reference sites. The station location must allow for completing the observation loop within 12 hours.
- Class 2 needs to be located along the leveling lines on the existing NVN benchmarks at distances up to 60 km from reference sites.

2.4.4.2.2.2 Monumentation of relative gravity control points

The requirements for the monumentation of Class 0 and Class 1 relative gravity stations are the same as those needed for absolute gravity stations (see [Section 2.4.4.1.2.2](#)).

The requirements for the monumentation of Class 2 and Class 3 relative gravity stations are the same as the requirements for NVN benchmarks (see [Section 2.3.3.3.3](#)).

2.4.4.2.2.3 Relative Gravity Instrumentation and Calibration

Relative gravimeters need to operate reliably and accurately in harsh field conditions, outdoors, and in any weather.

The main instrument requirements are listed below:

- Microprocessor-based, fully automated, digital.
- Automatic leveling.
- Power supply included.
- Temperature controlled.
- Protected from changes in ambient conditions (temperature, pressure, etc.).
- Automated corrections (tide, instrument tilt, temperature, pressure, drift, noisy sample, seismic noise filter, etc.)
- Reading resolution of at least 1 μGal .

Accuracy requirements for a relative gravimeter depending on the class of measurements are listed in Table 21.

Table 21: Accuracy Requirements for Relative Gravimeters

Parameters	Class 0	Class 1	Class 2	Class 3
Minimum instrument internal error, (μGal)	10	10	20	20

Relative gravimeters require periodic calibration in order to check stability and reliability. The requirements for the calibration procedure are as follows:

The gravimeters should be calibrated once a month during fieldwork. For this purpose, an appropriate pair of higher-class sites can be used. In case a deviation in calibration is detected, the gravimeter must be calibrated on a high-accuracy gravity calibration baseline.

- If calibration is performed utilizing a gravity calibration baseline, both the inside and outside markers at the site need to be included.
- The calibration observation sequence is as follows:

A1-A0-A1-A0-B0-A0-B0-B1-B0-B1-A0-A1

A0, A1 – indoor and outdoor stations of calibration site A;

B0, B1 – indoor and outdoor stations of calibration site B.

- Calibration measurements are processed in one run for each gravimeter, using the least square (or other robust) estimation technique to determine drift and calibration parameters.
- Calibration measurements and processing results for each gravimeter must be well documented.

The calibration-related threshold values in KSA are based on the NGS standards ([Federal Geodetic Control Committee, FGCC, 1984](#)) and are given in Table 22.

Table 22: Relative Gravimeter Calibration Requirements

Parameters	Class 0	Class 1	Class 2	Class 3
Necessary for the user to determine the calibration model	Yes	Yes	Yes	Yes
Allowable uncertainty of calibration model (μGal)	5	5	10	10
Allowable uncertainty due to external air temperature changes (μGal)	1	1	3	3
Allowable uncertainty due to external air pressure changes (μGal)	1	1	2	2

Allowable uncertainty due to other factors (μGal)	3	3	5	5
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2.4.4.2.2.4 Relative Gravity Observation Procedure

The observation procedure utilizing a digital relative gravimeter is as follows:

- Carefully remove the instrument from the case and set it up on the station. Using the reference leg, orient the instrument the same way as was done on the previous stations.
- Level the instrument using adjustment screws of two other non-reference legs, avoid using the reference leg for the leveling of the instrument.
- Protect it from direct wind and sunlight using a portable enclosure (if needed).
- Measure the height from the bottom of the instrument to the top of the site marker, the standard deviation should be less than 1 mm.
- Leave the instrument to stabilize for 1 - 2 minutes.
- Start measurements with each reading having a duration of 60 seconds and with a minimum interval of 15 minutes for the entire set of readings.
- Remain at a minimum distance of 10 m from the instrument during the reading.
- Maintain a separate survey log sheet for each tie leg and include site number, all gravity readings, reading times, standard deviations, average gravity with repeatability and uncertainty, instrument height, and relevant notes.
- If a stop of more than one hour is made during transportation, make a drift observation of gravity at the start and end of the stop. Record the gravity values, time, and location of the drift station.

2.4.4.2.2.5 Relative gravity data processing

The processing of relative gravity data aims to apply all the necessary corrections and to compute mean gravity values per observation loops.

The main requirements for data processing are listed in Table 23 below.

Table 23: Relative Gravimeter Processing Requirements

Parameters	Class 0	Class 1	Class 2	Class 3
Maximum standard error of a gravity value (μGal)	20	20	20	20
Total allowable instrument uncertainty (μGal)	10	10	20	20
Uncertainty of atmospheric mass model (μGal)	0.5	0.5	0.5	0.5
Uncertainty of lunisolar attraction (μGal)	1	1	5	5
Uncertainty of Earth's elastic and plastic response to tidal loading (μGal)	2	2	5	5
Loop closure by average corrected gravity differences (μGal) (m – number of sites in the loop)	$4.8\sqrt{m}$	$4.8\sqrt{m}$	$5\sqrt{m}$	$5\sqrt{m}$
Loop closure by average corrected gravity differences by each gravimeter (μGal) (m – number of sites in the loop)	$8\sqrt{m}$	$8\sqrt{m}$	$10\sqrt{m}$	$10\sqrt{m}$

The following corrections need to be applied during the processing stage:

- Earth tides.
- Atmospheric pressure.
- Polar motion.
- Tilt.

The description of these corrections is provided in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)). In addition to the corrections listed above the gravity value needs to be corrected for the difference between the height of the station and the height of the point where the measurements are carried out using Equation (5):

$$\delta g_h = 3.086 \cdot \Delta H_{red} \quad (5)$$

where 3.086 is the free air gradient in ($\mu\text{ms}^{-2}/\text{m}$); and ΔH_{red} is the height difference between the height of the point where the measurements are carried out, such that:

$$\Delta H_{red} = H_i + \Delta H_{total} - \Delta H_{sys} \quad (6)$$

where H_i is the height of the gravimeter; ΔH_{total} is the height difference from the gravity meter bottom to the upper edge (as measured by the user); and ΔH_{sys} is the vertical position of the internal reference point.

2.4.4.2.2.6 Relative gravity adjustment

The adjustment of a relative gravity network should be done with respect to one or more reference stations utilizing the least squares adjustment method.

The least squares procedure for relative gravity adjustment is described in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

2.4.4.2.2.7 Relative Gravity Publication / Submission

The reporting materials and deliverables for the relative gravity observations are of the same content as for the absolute gravity, which is described in [Section 2.4.4.1.2](#).

2.5 National Permanent Geodetic Stations

2.5.1 Continuously Operating Reference Station (CORS)

A Continuously Operating Reference Station (CORS) is a permanent ground reference station located at a point with a precisely known 3D location on the Earth's surface and equipped with a GNSS receiver and antenna that continuously collects GNSS data. The data collected by networks of GNSS CORS can be used for scientific purposes such as station coordinate and velocity estimation, computation of satellite orbit and clock corrections, regional ionospheric models, zenith tropospheric delays, and more, and at the same time can be used for dissemination of real-time differential corrections to support users carrying out high-precision surveys.

Guidelines and guidelines covering the various elements of CORS are separated into three categories based on the intended contribution of the CORS, which are specified in .

2.5.2 Tide Gauge Station (TG)

A tide gauge is a system for observing the height of the sea level relative to the height of the land. Tide gauges are commonly used by coastal nations to measure sea level and use it as a reference for a vertical datum.

Tide gauge installation and calibration procedures are described in the Guidelines for Hydrography for the Kingdom of Saudi Arabia ().

Tide gauge installation needs to be either co-located with a GNSS CORS to estimate ellipsoidal height at the TG location or in the absence of GNSS data, satellite altimetry can be used for that purpose, see [Section 2.6.2](#). Satellite altimetry data can be combined with leveled height differences, geoid heights, and gravity observations to estimate the geopotential differences/offsets at the TG locations.

2.5.2.1 Tide Gauge connection to KSA-VRF14

TG stations need to be linked to KSA-VRF benchmarks using geodetic leveling as described in [Section 2.4.2](#). For Primary order, the leveling needs to be carried out with respect to Class 0.

A TG deformation network needs to include:

- Four tide gauge benchmarks (TGBM).
- Two tide gauge reference points (TGRP).
- One NVN benchmark to provide connection to the NVN.

Procedures on how to carry out TG deformation surveys and how to conduct precise leveling to a tide gauge are described in the GEOSA Geodetic Survey Guidelines ([General Authority for Survey and Geospatial Information, GEOSA, 2024](#)).

Guidelines and guidelines covering all aspects of TG installation and operation are separated into three categories, based on the intended contribution of the TG and are shown in Table 27.

Table 27: Tide Gauge Guidelines by Intended Contribution

Contribution	Description	Primary Guidelines	Secondary Guidelines
International	The primary contribution of the TG is to support sea-level research at local, national, and global scales.	IOC (2016) Manual on Sea Level Volume V: Radar Gauges	IOC (2006) Manual on Sea Level Volume IV: An Update to 2006
National/ Regional	The primary contribution of the TG is to define and maintain a national vertical datum or scientific research.	ICSM (2021) Australian Tides Manual Special Publication No. 9	NOAA (2013) Co-ops Specifications and Deliverables for Installation, Operation, and Removal of Water Level Stations
State / Local	The primary contribution of the TG is to define and maintain a port datum, often supporting real-time applications.	ICSM (2021) Australian Tides Manual Special Publication No. 9	NOAA (2013) Co-ops Specifications and Deliverables for Installation, Operation, and Removal of Water Level Stations

2.5.3 Space Geodetic Stations

Apart from GNSS, other space geodetic techniques such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) can help to contribute to the realization of the International Terrestrial Reference Frame (ITRF), monitoring of the Earth rotation, and monitoring of the motions of tectonic plates.

Currently, KSA does not have any VLBI, SLR, or DORIS stations, however, in the future one or more of these stations may be built. If/when this happens, these guidelines will need to be updated to reflect that change.

A short description of each technique is provided below.

2.5.3.1 Satellite Laser Ranging (SLR)

SLR is used to measure the time of flight of a laser to reach a satellite and return to the Earth. The technique can be used to uniquely define the Earth's center of mass and, along with VLBI, the scale of the Earth. It is also used to help compute Earth Orientation Parameters (EOPs) of polar motion (pole coordinates) and the rapid variations in length-of-day (LoD). SLR is also the most accurate way to resolve the center of satellites which helps to calibrate radar altimeters and separate long-term instrumentation drift from secular changes in ocean topography.

2.5.3.2 Very Long Baseline Interferometry (VLBI)

Very Long Baseline Interferometry (VLBI) is a technique that detects radio transmissions from extragalactic radio sources. Using the difference in time at which the signals from the source arrive at different radio telescopes, it is possible to determine EOPs, Universal time (UT1), polar motion (pole coordinates), and precession and nutation. Along with SLR, VLBI is also used to measure the scale of the Earth.

2.5.3.3 Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS)

DORIS is a system that can determine the distance between a ground station and a satellite. It is based on accurate measurements of the Doppler shifts on a radiofrequency signal emitted by ground stations and received onboard different satellites carrying DORIS receivers. A ground segment monitors and processes the data and scientific products distributed by the International DORIS Service. Since the position of the ground stations is known, DORIS allows precise determination of the satellite orbits.

2.6 Geodetic Earth Observation (GEO) Techniques

Geodetic Earth Observation (GEO) techniques include satellite gravimetry and altimetry that have been actively used for various aspects of SANSRS definition, as well as emerging techniques such as Interferometric Synthetic Aperture Radar (InSAR) that can be used to measure deformation at a local scale.

Guidelines for these techniques are not as mature as other geodetic techniques described in . For this reason, these techniques are only briefly described in this section.

2.6.1 Satellite Gravimetry

Satellite gravimetry utilizes the principle of interacting masses, those being, in this case, the mass of the Earth and that of an orbiting satellite. This interaction causes perturbations of the satellite orbit which can be measured in order to draw conclusions about the gravitational forces acting on the satellite.

The main observation principles for satellite gravimetry are:

- Satellite-to-satellite tracking in high-low mode: A Low Earth Orbiting (LEO) satellite is tracked by high orbiting GNSS satellites, relative to a network of ground stations. The LEO satellite is a probe within the Earth's gravity field, which can be precisely tracked without interruption. The observed 3D accelerations correspond to the gravity accelerations. The non-gravitational forces acting on the satellite are measured by accelerometers and accounted for.

- Satellite-to-satellite tracking in low-low mode: Two LEO satellites are placed in the same orbit, separated by several hundred kilometers, and the distance between them is measured with the highest possible accuracy. Acceleration differences between the two satellites are measured by changes in the inter-satellite distance. The two satellites can be considered as one instrument in which (1) Variations in the gravity field cause variations in the range between the two satellites. Areas of stronger gravity affect the lead satellite first and accelerate it away from the second satellite, (2) Range variations are measured by high-accuracy microwave link or laser-ranging interferometry, (3) The observed range variations are corrected for non-gravitational effects by precise accelerometers. This method provides higher sensitivity than the previous one.
- Satellite gravity gradiometry: Acceleration differences in all three dimensions are measured directly within a LEO satellite using an on-board gradiometer. One important advantage is that non-gravitational accelerations are the same for all measurements inside the satellite and hence vanish by differentiation. Data provided by satellite gravity field missions are essential for the determination of the Earth's gravity field, the computation of global and regional geoids, the unification of vertical datums, and the establishment of global and national VRFs ([Global Geodetic Observing System, GGOS, 2023](#)).

2.6.2 Satellite Altimetry

Satellite altimetry is a technique for measuring the distance between an orbiting satellite and the instantaneous sea surface using the transition of microwave pulses in the radar frequency domain or laser pulses in the optical or infrared domain. Since the satellite's altitude is known, the sea surface height can be derived as the height of the instantaneous sea surface above the reference ellipsoid.

The main contribution of satellite altimetry is the ability to map large ocean areas within a short time period to obtain a representation of the sea surface with high spatial and temporal resolution. Current satellite altimetry missions provide sea surface heights with an accuracy of about 1 – 2 cm for a single measurement.

2.6.3 Interferometric Synthetic Aperture Radar (InSAR)

Interferometric Synthetic Aperture Radar (InSAR) is a geodetic method for detecting Earth surface displacements. It measures crustal changes related to geological phenomena like tectonic shifts and seismic activity. Additionally, it can detect ground subsidence due to activities such as groundwater extraction.

InSAR provides a way to observe ground surface deformation over small local areas very precisely. Given that this type of deformation can be highly variable, and is often non-linear, it cannot be adequately monitored using sparse GNSS stations. However, if InSAR is integrated with GNSS observations, it can achieve high spatial resolution, enabling the identification of surface movements at scales ranging from millimeters to centimeters.

InSAR is currently not used in KSA for SANSRS definition or maintenance, however, it could be included in the future, in which case this Guideline will need to be updated.

2.7 Network Adjustment – General Principles

2.7.1 Purpose

For geodetic control surveys, the least squares adjustment technique provides a reliable means for estimating the most probable survey control mark coordinates and accuracies from a redundant set of measurements by applying well-understood and agreed functional and stochastic models. The technique of least squares also provides a rigorous means for statistically testing and validating the estimated coordinates and the measurements used to derive them, thereby allowing the detection and elimination of measurement outliers.

2.7.2 Recommended Procedures

Control surveys undertaken to derive the horizontal and vertical position of survey control marks relative to SANSRS should be adjusted using a rigorous least squares adjustment process. The following procedures are recommended:

- (a) All survey control measurements should be corrected using known calibration parameters and other systematic errors accounted for. Measurements should be accompanied by reliable values of uncertainty (standard deviations). To test a control survey for errors, sufficient redundant measurements must be incorporated into the survey control network. Increased redundancy (quantified by the degrees of freedom in the network) leads to increased confidence in the testing results.
- (b) A minimally constrained adjustment should be performed and tested using the local test (see [Section 2.7.3.1](#)) and global test (see [Section 2.7.3.2](#)) to remove outliers and validate the appropriateness of the stochastic model. If the stochastic model is deemed inappropriate, the stochastic model should be corrected (e.g. by scaling) before continuing.
- (c) The uncertainty of the least squares outputs (e.g. coordinates) should be examined to assess whether the survey has achieved any predefined thresholds.
- (d) Once an acceptable minimally constrained adjustment has been completed, a fully constrained adjustment, using appropriately weighted constraints, must be performed. The fully constrained adjustment must not use “fixed” constraints or “known values” to assign infinite (or other inappropriate) weights.
- (e) The fully constrained adjustment should be tested using the local test (see [Section 2.7.3.1](#)), to verify that the imposed constraints do not result in measurement failure(s).
- (f) The fully constrained adjustment should be tested using the global test (see [Section 2.7.3.2](#)). If this adjustment test fails, the constraints need to be examined to identify and rectify the cause of failure.
- (g) The uncertainty of the least squares outputs (e.g. coordinates) should be examined to assess whether the survey has achieved any predefined thresholds.

2.7.3 Statistical Testing

Statistical tests in a network adjustment are used to identify and eliminate measurement outliers, validate the stochastic model applied to the measurements, and assess and/or demonstrate the overall accuracy of a survey control network. The following two tests should be undertaken on both minimally constrained and fully constrained adjustments.

2.7.3.1 Local Test

The local test is an evaluation procedure performed on individual survey measurements to assess the quality of a measurement and its assumed (*a priori*) standard deviation. This is done by assessing the magnitude of each measurement correction against an appropriate test statistic (such as the normalized residual) at an appropriate confidence interval (usually 95%). Such testing should be undertaken to demonstrate that:

- Any gross errors within the measurement set are identified and eliminated.
- All measurements are appropriately weighted.
- In the case of constrained adjustment, the imposed constraints do not put undue strain on the measurements.

2.7.3.2 Global Test

The global test assesses the quality of the survey as a whole. A single test statistic is computed and assessed at an appropriate confidence level (usually 95% confidence). Statistical failure of the global test indicates either the presence of significant outliers and/or an inappropriate stochastic model has been applied to the measurements.

2.7.4 Quantifying Accuracy

Refer to [Section 2.1](#) for information on the conventions used by GEOSA to express the accuracy of a least squares adjustment.

3. Supplementary Informative Elements



3.1 Annex A – Examples of passive NGN and NVN Control Points



Figure 6: Absolute gravity point



Figure 7: Absolute gravity point



Figure 8: Benchmark type 1



Figure 9: Benchmark type 2



Figure 10: Geodetic pillar type 2



Figure 11: Geodetic pillar type 1

3.2 Symbols, Acronyms and Abbreviations

Symbols, Acronyms and Abbreviations	Definition
BFFB	Backward-Forward-Forward-Backward
BM	Benchmark
CORS	Continuously Operating Reference Station
DGNSS	Differential GNSS
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
DR	Double-Run
EOP	Earth Orientation Parameters
FGCC	Federal Geodetic Control Committee
FGDC	Federal Geographic Data Committee
GBN	Gravity Base Network
GCB	Gravity Calibration Baseline
GEO	Geodetic Earth Observation
GEOSA	General Authority for Survey and Geospatial Information
GGOS	Global Geodetic Observing System
GNSS	Global Navigation Satellite System
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GRS80	Geodetic Reference System 1980
HOI	Higher Order Ionospheric
IBP	International Best Practices
ICSM	Intergovernmental Committee on Surveying and Mapping
IGS	International GNSS Service
InSAR	Interferometric Synthetic Aperture Radar
IOC	Intergovernmental Oceanographic Commission
ITRF	International Terrestrial Reference Frame
JCGM	Joint Committee for Guides in Meteorology
KSA-GEOID21	KSA National Geoid Model 2021
KSA-GRF17	KSA Geodetic Reference Frame 2017
KSA-VRF14	KSA Vertical Reference Frame 2014
LEO	Low Earth Orbit
LoD	Length-of-Day
NGN	National Geodetic Network

NGrN	National Gravity Network
NGS	National Geodetic Survey
NTGN	National Tide Gauge Network
NVN	National Vertical Network
PGRN	Primary Gravity Network
PPP	Precise Point Positioning
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RINEX	Receiver Independent Exchange Format
RTK	Real-Time Kinematic positioning
SGN	Secondary Gravity Network
SI	Système International - The International System of Units (SI) is the metric system that is used universally as a standard for measurements.
SLR	Satellite Laser Ranging
SP	Spur
SPP	Single Point Positioning
SR	Single-Run
SRDS	Single-Run, Double Simulations
STD	Standard Deviation
TG	Tide Gauge
TGBM	Tide Gauge Benchmarks
TGRP	Tide Gauge Reference Points
UT1	Universal Time
VLBI	Very Long Baseline Interferometry
ZTD	Zenith Tropospheric Delay

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