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BUREAU OF INDIAN STANDARDS

WIDE CIRCULATION DRAFT FOR COMMENTS ONLY

मसौदा भारतीय मानक

जियोडेटिक संदर्भ फ्रेम स्थापित करने के लिए विनिर्देश और अभ्यास

Draft Indian Standard

Specifications and Practices for establishing Geodetic Reference Frame

ICS 35.240.70

LITD 22 Geospatial Information Sectional Committee	**Last Date for Comments: 17th September 2025**

Geospatial Information Sectional Committee, LITD 22

FOREWORD

(Formal clause will be added later)

Accurate surveying and mapping require a well-defined Geodetic Reference Frame for horizontal, vertical, and gravity control, ensuring consistency across various applications such as land management, infrastructure development, environmental monitoring, and national security. Since the Earth’s surface is highly irregular, ranging from Mount Everest (+8,848m) to the Dead Sea (-429m), a mathematical approximation using ellipsoids has been adopted for mapping. Over time, different countries have used various non-geocentric ellipsoids (e.g., Everest Ellipsoid in India, Clarke 1880 in South Africa) to simplify geospatial calculations. Today, with the advent of satellite geodesy, reference frames have shifted to global and geocentric systems, aligning with the Earth's center of mass for accurate positioning.

In addition to the ellipsoid, another crucial reference surface is the geoid, which represents the equipotential gravity surface best fitting mean sea level. Unlike the ellipsoid, the geoid accounts for gravity variations, making it the preferred reference for elevation measurements and water flow analysis. Vertical heights (H) are commonly referenced to the geoid-based vertical geodetic datum, ensuring consistency in elevation data. Gravity measurement, essential for both geodesy and geophysics, has been standardized worldwide. In India, gravity observations date back to 1865, with modern gravity networks based on the International Gravity Standardization Network (IGSN 71), adopted globally in 1971.

For vertical control, India relies on Mean Sea Level (MSL), determined from 18.61 years of tidal observations at various coastal stations. Tidal height measurements, referenced to chart datums, are crucial for maritime navigation, coastal development, and geodetic studies. Various tide gauges are used, and standardization of tidal measurement techniques remains an ongoing need to ensure consistency and accuracy.

The composition of the Committee responsible for formulation of this standard is given in Annex XXXX.

Table of Content

Doc No.: LITD 22 (27935)
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Indian Standard

SPECIFICATIONS AND PRACTICES FOR ESTABLISHING GEODETIC REFERENCE FRAME

1 SCOPE

This Indian standard specifies the minimum requirements for determining the position and uncertainty of India's Survey Control Marks and Gravity, Tidal and Geomagnetic observation. It also provides guidance for establishing a Geodetic Reference Frame encompassing Horizontal, Vertical and Gravity Control to ensure accurate and consistent geospatial measurements.

The provision of this standard for expressing uncertainty have been developed primarily for datum control services but are also intended to be adopted, where possible for all form of general purpose control surveys.

2 REFERENCE

The references will be added later, if any.

3 TERMS, DEFINITIONS, ABBREVIATIONSAND NOTATIONS

3.1 Terms and Definitions

For the purpose of this Standard, the following terms and definitions shall apply

3.1.1 *Accuracy:* The level of closeness of an estimated value measured or computed - of a quantity to its true or accepted value.

3.1.2 *Chart Datum (CD):* Chart Datum is the reference level used on nautical charts to measure water depths and tidal heights, typical based on the lowest astronomical tide. It's an imaginary plane below which lowest low water seldom falls.

3.1.3 *Conventional International Origin:* It is the mean position of polar/ axis of the rotation of the earth between 1900 and 1905.

3.1.4 *Continuously Operating Reference Station:* A survey control mark hosting a permanent Global Navigation Satellite System station.

3.1.5 *Conventional Tide Gauge:* Conventional Tide Gauge is a float type instrument which record tidal data on a graphic paper.

3.1.6 *Datum:* An official, fully-defined, spatial reference system or surface to which measurements and/or coordinates upon the Earth may be defined and related.

3.1.7 *Datum Corrections:* Datum correction in tidal charts is an adjustment made to account for differences between the true zero and working zero less than least count of tidal charts.

3.1.8 *Eötvös effect:* The Eötvös effect refers to the variation in the apparent gravitational acceleration experienced by a moving object due to the Earth's rotation.

3.1.9 *Geoid:* The equipotential surface of the Earth's gravity field which best fits global mean sea level.

3.1.10 *Geodetic Reference System 80 (GRS80):* This reference ellipsoid defines the size and shape of the Earth with precise values for parameters like the semi-major axis (a = 6378137 m) and the flattening (f = 1/298.257222101).

3.1.11 *Highest Astronomical Tide:* It is the highest level that the sea is predicted to reach under normal meteorological conditions and under the gravitational influence of the moon and the sun. It's used as a reference point for assessing the potential maximum water level in coastal areas.

3.1.12 *Highest High Water:* It is the highest level reached by the sea during each tidal cycle, typically occurring twice a day, and it's used as a reference point for tidal measurements and marine navigation.

3.1.13 *Indian Geospatial Reference System:* India's collection of datums, models, standards and infrastructure which enable accurate and reliable 3D positioning, gravity, tidal and geomagnetic measurement.

3.1.14 *International System of Units (SI):* The International System of Units (abbreviated SI from French: Système International d'Unités) is the modern form of the metric system.

3.1.15 *International Earth Rotation Systems Service (IERS) Reference Meridian:* It is the prime meridian (0° longitude) maintained by IERS. It passes about 5.3 seconds east of George Biddell Airy's 1851 transit circle which is 102 metres (335 ft) at the latitude of the Royal Observatory, Greenwich. Thus it differs slightly from the historical Greenwich meridian.

3.1.16 *Lowest Astronomical Tide:* It is the lowest level that the sea is predicted to reach under normal meteorological conditions and under the gravitational influence of the moon and the sun, serving as a reference point for measuring depths on nautical charts. Some places it is using as a Chart datum also.

3.1.17 *Lowest Low Water:* It is the lowest level reached by the sea during each tidal cycle, typically occurring twice a day, and it serves as a reference point for tidal measurements and marine navigation.

3.1.18 *Mean Low Water:* It is the average height of the low tide over a specific period of time, usually calculated over a 19-year cycle. It serves as a reference level for determining water depths, coastal construction regulations, and other navigational and legal purposes.

3.1.19 *Mean Sea Level:* It is the average hourly tide height above CD of tidal station for 18.61 years. In 18.61 years, moon which is predominant force for tides, reoccupies its position in universe.

3.1.20 *Mean Tide Level:* It is the average height of the sea surface at any given location over a specific period, typically 19 years, used as a reference for tidal measurements and marine navigation.

3.1.21 *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.

3.1.22 *Time correction:* In tidal charts refers to adjustments made to account for differences between the times listed on the chart and the actual local time. These corrections ensure accurate timing of tidal events, such as high and low tides.

3.1.23 *True zero:* In tide gauge observation refers to the reference point (Fixed value of Bed plate) where the water level is measured without any tidal variations, atmospheric pressure effects, or instrument errors.

3.1.24 *Working zero:* In tide gauge observation refers to the reference point used for practical measurements, accounting for factors like instrument errors, atmospheric pressure, and tidal variations. It serves as a baseline from which actual tidal measurements are taken, ensuring accurate data collection.

3.1.25 *Zero Measurement:* In tide gauge observation in manual refers to the initial reference point (Bed Plate of Tide Gauge) or baseline from which all tidal measurements is taken. It represents the water level at a specific point or Bed Plate in time when there are no tidal variations or influences.

3.2 Abbreviations

CD: Chart Datum

CORS: Continuously Operating Reference Station

CTG: Conventional Tide Gauge

gpu: geopotential unit
1gpu= 1Kgal metre
=100000 $cm^2 s^{-2}$
=10 $m^2 s^{-2}$

HP: High Precision

IAG: International Association of Geodesy

IGRS: Indian Geospatial Reference System

ITRF: International Terrestrial Reference Frame

LAT: Lowest Astronomical Tide

MSL: Mean Sea Level

PTG: Pressure Tide Gauge

RIVD: Redefined Indian Vertical Datum

RTG: Radar Tide Gauge

SBM: Standard Bench Mark

4 GEODETIC REFERENCE FRAME

The Geodetic Reference Frame (GRF) provides a precise foundation for mapping, navigation, and infrastructure planning by ensuring accurate measurements of locations and elevations. When surveying and mapping large areas, it is essential to establish a GRF for horizontal, vertical, and gravity control, which offers a consistent reference for all surveying and mapping activities. The following section defines the technical specifications for establishing and maintaining geodetic control points (GCPs and CORS), the computational methods for height adjustments, and the observational protocols for gravity, tidal and geomagnetic measurements. This process involves maintaining tidal and levelling standards through regular benchmark and tide gauge checks, followed by gravity and geoid modelling to account for Earth's uneven gravitational field. Additionally, geodetic control surveys establish a network of fixed reference points, ensuring consistency in spatial data. Together, these steps create a reliable framework for accurate geospatial analysis, supporting applications in land development, disaster management, and environmental monitoring.

By adhering to this standard, geospatial professionals can achieve precise and reliable geodetic positioning, supporting India's geospatial infrastructure and scientific advancements.

5 STEPS TO ESTABLISH GEODETIC REFERENCE FRAME

5.1 Datum and Geodetic reference frame

Survey control marks established via Geodetic Control Survey and general purpose control surveys for the IGRS shall be coordinated relative to the datum and Reference Frame Set out below:

5.1.1 *National static geodetic datum*

The static geodetic datum is the Geocentric WGS-84 ellipsoid having

a= 6378137m (Earth's semi-major axis)

ω= 7.292115× 10^{-5} rad s^{-1} (Earth's rotation rate)

f= 1/298.257223563 (Flattening factor)

GM=398600.4418 km^3s^{-2} (Gravitational constant for Earth)

5.1.2 *Geospatial Reference Frame*

a) To align with international geospatial frameworks, GCPs and CORS shall be referenced in latest ITRF and recent epoch. However, for land management and cadastral applications, coordinates of GCP and CORS in ITRF2008 at epoch 2005 shall be used.

b) For Indian Geospatial Reference System, the height datum is Redefined Indian Vertical Datum which corresponds to the Local Mean Sea level (LMSL) at Apollo Bunder Tidal Observatory, Mumbai, which serves as the fundamental base for height adjustments (detailed justification is provided in Annex A).

5.1.3 To improve the accuracy of elevation measurements, the Helmert Orthometric Height computations are required. These computations account for Earth's gravity variations and ensures that the elevation data is corrected. Since gravity affects how we measure height, these computations help correct discrepancies and provide more reliable elevation data. The listed assumptions simplify the calculations:

Average density of rock = 2.67 g cm^{-3}

Actual topographic effect is not considered.

Gravity anomaly gradient is neglected.

5.1.4 The levelling network is established to ensure reliable height measurements and shall be planned along the coastal region of India while considering the following points:

a)	Type of Levelling	High Precision
b)	Maximum closing error of a circuit	0.2504 gpu
c)	Minimum closing error of a circuit	0.0010 gpu
d)	Instruments used	First order instrument Trimble Dini-12 and Leica DNA-03 digital levels having height measurement accuracy (Standard deviation per 1 km) of 0.3 mm using bar coded invar staff.
e)	Base	Average I.M.S.L. from 1976 to 1994 of Mumbai tidal observatory.
f)	Weights	$= 1/se^2$ where $se$is standard error, derived by Wassef's formula for each levelling line

5.1.5 The adjustment of geopotential number (GPN) in the levelling network follows the Least Squares Adjustment method using observation equations. The reference benchmarks are 2PP (Primary Protected) Standard Type 'P' Benchmarks at Mumbai, based on the vertical datum of tidal observatory at Apollo Bunder, Mumbai. The adjustment of the 11 Levelling Circuits are done one time by a Survey of India Levelling Adjustment Program (SOILAP). The mathematical foundation of SOILAP is based on the Least Squares Principle, which ensures that the sum of the squares of residuals is minimized for optimal accuracy.

5.1.6 The levelling network is classified as High Precision Levelling and shall adhere to the following error constraints as per Lallemand's formulae:

a) **Probable accidental error:** $\leq \pm$ **1.0mm/km**
b) **Probable systematic error:** $\leq \pm$ **0.2mm/km**
c) **Mean accidental and error: ≤ ±1.5 mm/km**
d) **Mean systematic error: ≤ ±0.3 mm/km**

These accuracy limits aligns with the standards adopted at the 1912International Geodetic Association Conference.

In order to estimate the levelling accuracy, the observed height differences are statistically analyzed to see distribution of probable systematic and probable accidental errors across the network and individual levelling lines and is computed using the following given formula:

For the probable accidental error, η_r, in the case of a set of lines, whether or not they form circuit:

$$\eta_r = \frac{1}{9}\left[\frac{\Sigma\Delta^2}{\Sigma L} - \frac{\Sigma r^2}{(\Sigma L)^2}\Sigma\frac{s^2}{L}\right]$$

(ii)For the probable systematic error, σ_r or σ_R:

(a) In the case of a set of lines not forming a network:

$$\sigma_r^2 = \frac{1}{9\Sigma L}\Sigma\frac{s^2}{L}$$

(b) In the case of a network allowing at least 10 circuits:

$$\sigma_R^2 = \frac{1}{\Sigma L^2}\left[\frac{2}{9}\Sigma f^2 - \eta_r^2\Sigma L\right]$$

(iii) For the mean accidental error, or for the mean systematic error, the same formulas as above only after multiplying the right hand side by 9/4.

Where:

L = The length of an unconnected line, or the length of the side of a circuit in the case of a net.

ΣL =The aggregate length of the set of lines, or of the net under consideration.

Δ =The discrepancy between the results of the two runnings between consecutive bench marks.

r =The distance between these two bench marks.

s =The entire discrepancy between the results of the two runnings, either for a whole line or for the side of a circuit.

Σf^2 =The sum of the squares of the errors of closure of the circuit, including the closing error, Σf, of the outside circuit.

The observations of all High Precision Levelling line shall also be checked statistically by calculating Probable accidental and systematic errors using the following formula:

Probable Systematic Error for a levelling line (e_s):

$$e_s = \frac{|S|}{3K}$$

Probable Accidental Error for a levelling line (e_a):

$$\boldsymbol{e_a} = \sqrt{\left(\frac{\sum \Delta^2}{9K} - e_s^2\frac{\sum r^2}{K}\right)}$$

Probable Error (p.e.):

$$p.e. = \sqrt{(e_a^2 K + e_s^2 K^2)}$$

S= ΣΔ

Δ = Discordance of fore and back levelling found between two consecutive bench marks

r = Distance between consecutive Bench Mark

K = Length of Levelling Line in Kilometres

5.1.8 In the absence of RIVD Survey Control Marks (Bench marks), height of Indian islands shall be clearly specified to refer at least of the following:
Locally determined MSL
or
Derived RIVD using India geoid model or equivalent geoid (or quasi geoid) model.

5.2 Gravity datum

India's journey in measuring gravity has progressed from pendulums to more recent and efficient gravimeters. This ongoing pursuit of accurate measurements not only contributes to the understanding of Earth's gravitational field but also plays a vital role in various geodetic applications. The gravity observations are measured in units of gal, where 1 gal = 1 cm/s^2

The current Indian gravity reference system, based on the International Gravity Standardization Net 1971 (IGSN71) (Bomford G., 1980), is facing limitations. Widely used, IGSN71 has an uncertainty level of 0.1 mGal, which doesn't meet the accuracy requirements for various scientific and practical applications. Additionally, IGSN71 was established in 1971, and since then, Earth's mass distribution has likely changed due to factors like mantle movements, earthquakes, and hydrological variations.

5.2.1 *Specifications for relative gravity surveys*

a) Max X and Y tilt after levelling- <10arcSeconds
b) Closing error- <100microGal per day, <300microGal for closing on known gravity value station.
c) Observations per stations-
    1) A set of 5 observations per station, each observation lasting for 1 minute.
    2) Difference between any of the consecutive observation shall be <10microGal
    3) If any observation has a difference of more than 10microGal with any of other observations, at least 3 consecutive observations are to be selected for calculating final value at that station. If not available, the set is to be repeated again.
d) Distance between two consecutive gravity stations in case of Levelling
    1) For plain and plateau areas, the maximum distance between two consecutive gravity observations on levelling benchmarks shall be less than 4-5 km.
    2) For hilly areas, the maximum distance between two consecutive gravity observations shall be on every levelling benchmark or within 1km distance.

5.2.2 *Specifications for absolute gravity surveys*

a) All checks and procedure as per Standard Operating Procedure are to be strictly followed for the Absolute Gravimeter.
b) Before going for field, pre-field acclimatization is to be done on any Type ‘P’ SBM having known gravity value or any gravity station.
c) System setting for pre-field acclimatization-
    1) Sets- 2 pairs of sets (4 sets)
    2) Drops per set- 20
    3) Sequence interval- 2 Hr.
d) System settings for field
    1) Orientation-2 orientations, 12 hours in North direction and 12 hours in south direction to minimize possible Eötvös effects.
    2) Sets- 12 pairs of sets in each orientation (48 sets)
    3) Drops per set- 60 nos.
    4) The pillars for absolute gravity observations shall have size 1m X 1m followed by 2m depth. It shall be placed in a pit surrounded by sand to provide dampening from earthquake vibrations. The pillar top shall coincide with the ground and shall be place in a room at least 3m X 3m wide.
    5) Vertical gradient is to be measured using relative gravimeter. According to IAG guidelines, 3 measurements with the relative gravimeter will be taken, at the marker (approximate), at 0.8m above marker and ranging from 0.8m to 1.1m above marker.

5.2.3 Methodology for relative gravity surveys is given in Annex B.

5.3 Tidal datum

a) Levelling shall occur annually to assess the bed plate's stability. The process, known as check levelling, must align with HP levelling parameters. This involves using precise instruments to measure horizontal and vertical alignment, ensuring they meet specified tolerances. Tolerance limit for vertical alignment is $3\sqrt{L}$ mm where L is the distance in Km from bed plate to the nearest HP levelling bench mark. Same for horizontal alignment is 3 mm.
b) Zero measurements, taken fortnightly, establish a baseline for tidal observations. The discrepancy between True Zero (a theoretical baseline) and Working Zero (adjusted for practical factors) shall be within ±2 cms to ensure accuracy. If Time and Datum corrections are necessary during Zero Measurement, they shall be applied to the recording chart to account for variations in timing and reference levels, maintaining the reliability of tidal data.
c) If any CTG, PTG or RTG is found to be malfunctioning, immediate rectification is necessary. This ensures the continuous and accurate monitoring of tidal conditions. Malfunctioning gauges can compromise the reliability of tidal data, which is critical for various applications such as navigation, coastal management, and disaster preparedness. Therefore, prompt rectification helps maintain the integrity of the monitoring system and ensures the safety of maritime activities and coastal areas.
d) Proper inspection and checkup of stilling wells are essential to ensure they remain free of siltation. Stilling wells are structures designed to house instruments like tidal gauges, and

they need to be clear of sediment to accurately measure water levels. Regular inspections help identify any build-up of silt or debris, which can affect the performance of instruments and lead to inaccurate readings. By keeping stilling wells siltation-free through routine maintenance and cleaning, the reliability of tidal data collection is maintained, supporting safe navigation and effective coastal management.

e) Analysis of ports tidal data shall be up to date to improve tidal constituents. New constituents shall compare with old constituents for percentage accuracy. Acceptance/ rejection shall be based on comparative statement.

f) Performing a 32-day tidal observation and analysis for each secondary port is crucial for understanding local tidal patterns and variations. This data collection helps in establishing accurate tidal predictions and updating tidal charts for navigation and coastal management purposes. Revising this observation and analysis every 19 years ensures that the tidal predictions remain up-to-date and reflect any long-term changes in tidal behaviour due to factors like sea level rise or coastal development. This periodic revision ensures the continued reliability of tidal information for safe maritime navigation and coastal planning.

g) Methodology for fixation of Chart Datum (CD) is annexed as Annex C.

h) Difference between Predicted and Actual values in time and heights shall be more than 90% confidence.

j) The permissible error between Conventional Tide Gauge, Pressure Tide Gauge, and Radar Tide Gauge shall be within ±2 centimetres. This precision is essential because 2 centimetres represents the least count of tidal charts for a tidal range of 3.8 meters.

k) Weekly comparisons shall be conducted between radar tide gauge (RTG) data and Conventional tide gauge (CTG) data to assess the quality of the RTG measurements. This process ensures that the RTG data accurately reflects tidal variations and is consistent with CTG data, which serves as a benchmark.

m) The installation of at least two types of tide gauges, comprising one conventional and one digital system, is mandatory at every tidal observatory. This dual-gauge setup not only provides redundancy for increased reliability but also combines the strengths of traditional and contemporary measurement methods, resulting in a more robust and versatile tidal observation system.

5.4 Geomagnetic datum

5.4.1 *Secular Variation*

Secular variation (changes) refers to the slow, long term changes in the earth's magnetic field typically on time scale of years and decades that are not related to rapid fluctuations in the ionosphere or magnetosphere. To determine the secular variation of magnetic entities, a network of secular stations or repeat stations with a distance of 100-150 km between points is needed. The area shall also be well controlled with a network of magnetic observatories. Measurements at these stations shall be made once in roughly 5 years, preferably during periods of low magnetic activity because the disturbances to the field of external origin are the minimum. If the secular changes start varying rapidly as it occurs in a focus of rapid secular points, such changes shall be measured every year. In choosing an observatory site, local anomalies shall be avoided whenever possible.

5.4.2 *Magnetic Observatory*

a) Besides studying the secular changes in the earth's magnetic field, an observatory is used for controlling the field magnetic survey.
b) The location of an observatory is chosen and maintained in such a way that no artificial magnetic disturbance affects the actual variation in earth's magnetic field i.e., real value & variations can be observed in pure artificial disturbance free environment. This is ensured by keeping at least 50 m of distance between the observatory buildings with each other and compound walls.
c) Further, no metallic objects are allowed near the observatory buildings, and the instruments are kept away at a distance such that they do not interfere with each other magnetically.
d) The observations in the observatory are done using high precision variometer and absolute magnetometer.
e) Thus, all the above ensures the consistency and reliability of the variometer data and baseline* prepared using absolute instruments.

5.4.3 *Geomagnetic instruments and measurements*

Geomagnetic instruments are classified as:

a) *Variometers:* - Which measure variation of the field with respect to a reference base value.
b) *Magnetometers: -* Which carry out measurements of the absolute value of the magnetic field. Instruments can also be classified as scalar which gives only the value of the field without its direction and vector, which record the field value in a definite direction. The Instruments contain basically two units the Magnetic Sensor which uses a basic principle of physics for sensing the magnetic field, and a magnetograph which gives a permanent record (magnetogram) of the magnetic force which the magnet sense. A magnetograph can be of Analogue type or Digital type.

5.4.4 *Observatory Instrument*

a) Digital Flux-Gate Magnetometer (DFM)

The flux-gate magnetometer type FGM-FGE is suitable for digital recording of the magnetic field at observatory. The Fluxgate magnetometer model FGE is tri-axial magnetometer. To improve long term stability as well as temperature stability these sensors are supplied with compensation coils wound on quartz tubes to obtain a sensor drift of less than a coefficient of 0.25NanoTesla per Degree Celsius(nT/ºC), which makes the magnetometer very well suited for use in magnetic observatories. It operates on 12 Volts Direct Current (V DC) power.

In the DFM the marble cubes are suspended in two crossed phosphor-bronze strips to compensate any tilt of the sensor foundation. With this baseline, drift of less than 2-3 nT/year has been obtained even at places where a normal fluxgate magnetometer would have shown drifts of 100nT/year or more.

5.4.5 *Field Magnetic Instrument*

a) Absolute Observations & Instruments

Absolute observations are carried out twice daily in order to control base line value of the three magnetic elements i.e. Horizontal Intensity (H), Declination (D) and Vertical Intensity (Z) components of Earth's geomagnetic field.

1) ENVI MAG
ENVI system is an easy to use, lightweight, battery powered, portable magnetometer. The magnetometer is a total field instrument using proton-precision techniques to measure the local field / total intensity.

2) MAG 01H
Declination Inclination Magnetometer (DIM)-to measure Declination and Inclination- The system permits very precise angular measurements of the terrestrial magnetic field F. The angular components measured are declination D(Variation) and Inclination I (dip). The value of F together with the components X (MM horizontal), Y and Z (vertical) may also be measured to an accuracy of 0.25%.

Performance: -

a) Measuring range: 0.1nT - 0.2 nT
b) Calibration Accuracy: 0.25%
c) Maximum resolution: 0.1 nT

b) Observation time & Agreement of Results with field instrument ENVI MAG & MAG 01H

At every repeat station, two sets of observation shall be taken i.e. one in morning and the other in the late evening with ENVI MAG & MAG 01H so that the Diurnal corrections are as low as possible specially in equatorial region 'H' increases sharply from three hour local time. The observation standards are given in table 1.

1) Agreement of 'F' values observed by ENVI MAG in the morning and evening shall not be more than ±35 ŋT at a particular station
2) Agreement of Declination / Inclination observed by MAG 01H in morning and evening shall not be more than ±5".
3) Observations with ENVI MAG & MAG 01H to be recorded manually in the observation register.

Table 1: OBSERVATION STANDARDS

COMPONENTS	D/I	H	Z
OBSERVATION PERMISSIBLE LIMIT (Morning/evening)	5"	30 nT	20nT

D/I: Dip/ Inclination
H: Horizontal Magnetic Field
Z: Vertical Magnetic Field

* Baseline: It is a reference absolute magnetic field measured in a day at a time. Variation in field is measured with reference to it in a day.

ANNEX A

(Clause 5.1.2)

1) Base for adjustment

The Apollo Bunder Tidal Observatory, Mumbai is adopted as base of Adjustment for the following consideration:

a) The Local MSL at Mumbai is the lowest and shall yield positive heights.
b) Mean value for LMSL has a low standard error of ±0.0035m and total range of variation in 38 years is only 8 cm.
c) The standard deviation of the slope parameter is minimum for Mumbai.
d) Effects of the under mentioned contributions have been removed as far as possible of Mumbai tidal observatory:
   1) Meteorological contributions:
      (i) Atmospheric pressure
      (ii) Wind
      (iii) Precipitation and evaporation
   2) Oceanographic contribution:
      (i) Water density
      (ii) Currents
   3) Hydrological contributions i.e. river discharge etc.
   4) Astronomical contributions:
      (i) The nodal tide effect with the period of 18.61 years
   5) Technical contributions:
      (i) Possible movements of gauge foundations
      (ii) Accidental errors in apparatus operations
      (iii) Reading errors
e) The results of determination of the Local Mean Sea Level at the Mumbai Port – an open coast station – have proved concordant, are not burdened with effects of channels, rivers, gulfs and creeks etc. and are closest to the average MSL trend of the Indian peninsula. Its acceptance as the vertical datum for the Indian sub-continent is therefore considered optimum.

ANNEX B

(Clause 5.2.3)

1) Methodology for relative gravity surveys

a) For preparation of geoid model, gravity observation is done on 3 types of benchmarks, first is on mesh in which the stations are 100km apart, second is on HP leveling line benchmarks and third on mesh with stations 10km apart on plains and 5km apart in hilly regions.

b) The 100km mesh points are kept as first order, the absolute values of which are to be surveyed from absolute gravity stations, present all around the country.

c) The 10km (or 5km) mesh points and HP leveling points are kept as second order stations, the absolute values of which are to be surveyed from 100km mesh points.

d) Before starting any observation, the relative gravimeter is levelled in both X and Y axis.

e) The relative gravity surveying is done in form of circuits, in which the first observation is done at the station with known absolute gravity value. For 100km points, it is either the nearest absolute gravity station or 100km point with known gravity value. For 10km (or 5km) and HP leveling benchmarks, the first observation is taken on 100km adjusted mesh point with known absolute value.

f) The observations in one circuit are continued by observing the next stations. The circuit for the day is closed by taking the observation on the first observed point of the day.

g) After the day's closing, first and last observations on the relative gravimeter of the opening station are compared and closing error is recorded. This closing error is then distributed to the other observed stations of that day linearly varying with time of observation. For example, if there is a difference of 100 units in first and last observation with a duration difference of 10 hours and suppose 3 observations are taken in between with a gap of 2 hours, 4 hours and 8 hours gap after first observation, therefore the correction for these three stations will be 20 units, 40 units and 80 units. This way the closing error correction is applied to the stations.

h) For leveling lines, these circuits are repeated by taking the first observation on the second last observed point of the circuit of last day. Finally, the full line is closed by observing at least one station with known absolute gravity value point in the last circuit. For 10km (or 5km) and 100km mesh points, same methodology is followed.

j) To adjust the observed gravity values, the absolute gravity value of known station in the closing circuit is calculated using absolute gravity value of known station in the opening circuit. The difference observed is distributed linearly to all the stations in a cumulative method.

k) The Co-ordinates of each station (Latitude, Longitude, Ellipsoidal height/MSL height) shall be correctly recorded on appropriate form (4 Grav form) along with full description.

m) The station of observation shall generally be on level ground (at least within a radius of 2 meters) and free from the rugged topography in the immediate vicinity, as far as possible. Observations on bridges and culverts shall be avoided as far as possible.

ANNEX C

(Clause 5.3)

1) Steps for fixation of Chart datum (CD)

a) Conduct a 32-day tidal observation to gather data on tidal patterns and variations.
b) Connect the observations with levelling data to establish a consistent reference level.
c) Compute the Chart Datum using either the Range Ratio method or the LAT method.
d) The Range Ratio method involves calculating the difference between the highest and lowest tides observed during the 32-day period and applying it to a known reference level.
e) The LAT method determines the lowest astronomical tide level and uses it as the Chart Datum.