هيئة كفاءة الإنفاق والمشروعات الحكومية
Expenditure Efficiency & Projects Authority

EXPRO National Manual for Projects Management

Volume 6, chapter 7

Surveying Guideline

Document No. EPM-KEC-GL-000005 Rev 003

Document Submittal History:

Revision:	Date:	Reason For Issue
000	29/10/2017	For Use
001	02/01/2018	For Use
002	19/11/2018	For Use
003	15/08/2021	For Use

THIS NOTICE MUST ACCOMPANY EVERY COPY OF THIS DOCUMENT

IMPORTANT NOTICE

This document, ("Document") is the exclusive property of Government Expenditure & Projects Efficiency Authority.

This Document should be read in its entirety including the terms of this Important Notice. The government entities may disclose this Document or extracts of this Document to their respective consultants and/or contractors, provided that such disclosure includes this Important Notice.

Any use or reliance on this Document, or extracts thereof, by any party, including government entities and their respective consultants and/or contractors, is at that third party's sole risk and responsibility. Government Expenditure and Projects Efficiency Authority, to the maximum extent permitted by law, disclaim all liability (including for losses or damages of whatsoever nature claimed on whatsoever basis including negligence or otherwise) to any third party howsoever arising with respect to or in connection with the use of this Document including any liability caused by negligent acts or omissions.

This Document and its contents are valid only for the conditions reported in it and as of the date of this Document.

Table of Contents

1.0 PURPOSE

This document provides guidelines to assist Surveyor for the survey work assigned by A/E. The guidelines apply to all survey work.

2.0 SCOPE

The guidelines apply to surveying of new projects.

3.0 DEFINITIONS

3.1 Definitions

Definitions	Description
Digital Terrain Model (DTM)	DTM represents the bare ground surface without any objects like plants and buildings
Digital Elevation Model (DEM)	Digital Elevation model is a three dimensional computer graphics representation of a terrain's surface created from a terrain's elevation data.
Digital Surface Model (DSM)	Digital surface model represents the earth's surface and includes all objects such as plants, buildings and etc., on it
Azimuth	The direction of a line through a point with respect to the meridian through the point expressed as the clockwise angle from north. Except where the line is along a meridian or the equator, the azimuth of a straight line changes as the point moves along the line.
US BLM	United States Bureau of Land Management
Northing	Second measurement of a grid reference used to specify the location of a point on a rectangular coordinate system. The distance measured northward from the origin of a rectangular coordinate system (corresponds to a “Y” coordinate in a Cartesian system).
Easting	First measurement of a grid reference used to specify the location of a point on a rectangular coordinate system. The distance measured eastward from the origin of a rectangular coordinate system (corresponds to an “X” coordinate in a Cartesian system).
Elevation	a value determined by measuring the height of a point relative to the datum
Latitude	It is the angular position of a place north or south of the equator. Positive values in the Northern hemisphere, negative in the South (i.e., the South Pole has latitude = - 90°).
Longitude	The angular location of a place on the Earth's surface measured east or west of the Prime meridian through Greenwich. Longitudes W are positive, E are negative.
Lot	The smallest piece of land to be used for a specific purpose; i.e., the lot to be occupied by a house, an apartment house, a business establishment, a mosque, pump station, reserve tract, etc.
Lot Line	Any line bounding a lot as herein defined.
Monument	A boundary or position marker.
Neighborhood Center	An area containing commercial and public facilities for a catchment area of approximately 10,000 to 15,000 people.
Parcel	A unit of land, or tract of land in a subdivision with specified location and boundaries, which is used or developed as a unit for a specific purpose.
Rectangular northing and easting coordinates	Rectangular northing and easting coordinates of any point give its positions with respect to an arbitrarily selected pair of mutually perpendicular reference axes. The Northing coordinate is the perpendicular distance, in meters, from the point to the Easting axis; the Easting coordinate is the perpendicular distance to the Northing axis.
Reserve tracts	Lots (or blocks) for future use, which use is unknown or cannot be defined at the time of subdividing; i.e., land which may be needed at a future date – for example expansion of a park, school grounds, commercial development, etc.

Definitions	Description
Right-of-way	Public land reserved for roads, sidewalks, pedestrian and bicycle paths, drainage and utility corridors, and pipelines.
Subdivision	A group of one or more blocks which lie within a geographically defined area, and where one or more of the blocks have been divided into lots, each lot to be used for a separate purpose.
Theodolite	A precision instrument for measuring angles to vertical and horizontal planes. Consists, in its most basic form, of a telescope which can rotate horizontally and vertically allowing readings to be taken from a calibrated circle. The instrument has to be centered over a fixed (control) point.
Traverse	A sequence of line segments of known length and direction that begin and end at the same point (closed loop), or begin and end at points whose relative positions have been determined by other surveys.
Triangulation	Using a network of triangles to accurately plot positions.
True Coordinate Position	The position of a point as determined by field survey originating from a known control survey marker of entity or any authorized agency, and performed to the precision and adjusted, as required for second order surveys.
Universal Transverse Mercator (UTM)	A grid system based upon the Transverse Mercator projection. The UTM grid extends North-South from 80°N to 80°S latitude and, starting at the 180° Meridian, is divided eastwards into 60, 6° zones with a half degree overlap with zone one beginning at 180° longitude. The UTM grid is used for topographic maps and geo-referencing satellite images.
Vertical Datum	A vertical datum is a surface of zero elevation to which heights of various points are referred in order that those heights are in a consistent system.

3.2 Abbreviations

The following abbreviations apply to this Section:

Abbreviations	Description
AMG	Automated Machine Guidance
ASB	As-Built
CUBE	Combined Uncertainty and Bathymetric Estimator
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Modeling
E	East
F.C.	Field Change
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IHO	International Hydrographic Organization
km	Kilometer
m	Meter
MBES	Multi-Beam Echo Sounder
N	North
NGS	National Geodetic Surveying (US)
NSPS	National Society of Professional Surveyors
PCC	Portland Cement Concrete
PPE	Personal Protective Equipment
RTK	Real Time Kinematic
S	South
SA.NGN	Saudi Arabian National Geodetic Network
SBES	Single-Beam Echo Sounder
TPU	Total Propagated Uncertainty
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
W	West

4.0 REFERENCES

4.1 General Requirements

The following is a list of design manuals which applies to this Section.

- MnDOT Surveying and Mapping Manual
  http://www.dot.state.mn.us/surveying/manuals.html

- Wisconsin Dept. of Transportation, Construction and Materials Manual, Chapter 7 Construction Surveying, Section 60 Staking Supplemental Control
  http://www.dot.state.wy.us/home/engineering_technical_programs/photos_and_surveys/SurveyManual.html

- Illinois Dept. of Transportation - Bureau of Design and Environment, Survey Manual, Chapter 6 Construction Surveys
  http://www.dot.state.il.us/desenv/survey/cover.pdf

4.2 Codes

- Saudi Arabia Survey Licensing Code

4.3 Standards

The following is a list of Standards which applies to this Section, refer to Volume 6, Chapter 5, Codes, Standards & References (EPM-KE0-GL-000014) for a list of additional Standards.

- NGS - National Geodetic Survey
  www.ngs.gov

- NSPS Model Standards for Construction Layout Surveys
  http://www.truenorthsurvey.com/wp-content/uploads/2010/04/NSPS-Standards-Construction-Layout-Surveys.pdf
- **General Authority for Survey and Geospatial Information** (GASGI)
  https://www.gasgi.gov.sa/en/pages/default.aspx

5.0 RESPONSIBILITY

It is responsibility of the Entity to ensure that survey is carried out as per the applicable requirements and standards.

6.0 PROCESS

6.1 Coordinate System

6.1.1 Type of Datum

There are currently two accepted datum used by the Ministries in the Kingdom of Saudi Arabia:

- Ain Al Abd Datum

  Saudi Arabian National Geodetic Network (SA.NGN) is based on Universal Transverse Mercator Projection System. The origin of the survey is at Ain Al Abd and the accepted origin data is as follows:

  1. Geodetic Latitude = 28 14' 06.171" (N)
  2. Geodetic Longitude = 48 16' 20.096" (E)
  3. Deviation of the vertical

a) In the meridian = +0.08"

b) In the prime vertical = +0.075"

4. Geoid-Spheroid separation: N = -8.4 meters
5. Spheroid (International) = HAYFORD 1910

a) Parameters

- a = 6378388 meters
- F = 1/297

The above Spheroid and origin information constitutes the "Ain Al Abd" (1970) Datum.

- World Geodetic System 1984 (WGS84)

  The World Geodetic System 1984 (WGS84) and Google Earth are currently using the same geographic coordinate system

Through GPS/GNSS surveys the geographic WGS84 coordinates are observed and usually transformed to the local coordinate systems such as Ain El Abed 1970 UTM38N or another system in Saudi Arabia. Transformation parameters are required to transform WGS84 to other datum and vice versa. Daily works are usually carried out in Cartesian coordinate systems, eg, UTM.

For transformations of coordinates in Ain El Abed 1970 UTM Zone to WGS84 and vice versa appropriate software, eg, ESRI, ARCMAP, Microstation, etc. has to be used.

6.2 Elevations and Survey Datum

6.2.1 Datum

The official datum shall be based on the published elevation of existing fundamental vertical control benchmarks, current at the time of the survey.

6.2.2 Measurements

Elevations can be measured using the following methods. The project accuracy requirements and specific equipment manufacturer's specifications will determine what method(s) are acceptable for the task.

- Differential levels using a digital level, spirit level or auto-level and graduated rod.
- Trigonometric levels calculated using measured vertical angles, such as measurements with a theodolite or total station, and measured horizontal distances.
- Global positioning using two or more GPS receivers.

Elevations shall be measured relative to a project benchmark with a known elevation. Prior to using the benchmark, the surveyor shall:

- Verify and use the official published elevation of the benchmark, current at the time of the survey.
- Determine if the benchmark was set with methods and procedures necessary to meet the required tolerances of the new measurements.
- Inspect the benchmark to ensure that it has not been disturbed.
- Check the elevation of at least one other project benchmark to verify:
  - The survey instrument is calibrated
  - The benchmarks have not been disturbed
- Check the elevation of at least two other points or features with a known elevation relative to the benchmark to determine if the new measurements will be consistent with the other site plan elevations, where applicable.

6.2.3 Field Notes

Daily field notes shall include:

- The date of the survey
- The elevation benchmark name and/or identifier used for the survey
- The benchmark elevation
- The condition of the benchmark at the time of the survey
- Any other notes of significance to the project such as if the benchmark is in danger of being disturbed or destroyed due to construction or other site conditions
- Electronic/digital field notes are encouraged and shall be used when working with data collectors. The use of day files for electronic note keeping shall be used. The instrument number, party chief and crew members shall be inputted as electronic notes. The time stamp function shall be turned on at all times.

6.3 Hydrographic and Tidal Data

6.3.1 Introduction

This Section provides guidelines for the performance of hydrographic surveys in port and harbor areas and offshore locations up to a depth of 30 m. Hydrographic surveys are generally undertaken for the following purposes:

- To maintain safe navigation conditions for vessels, by ensuring adequate under-keel clearances
- To provide control for dredging operations
- To allow monitoring of silt accumulation
- To locate existing structures, objects and obstructions
- To provide base mapping for design of proposed construction projects

6.3.2 Standard References

Hydrographic surveys will generally conform to accepted international and national Standards, including but not limited to the following:

- International Hydrographic Organization, Special Publication No. 44, 5th edition, *IHO Standards for Hydrographic Surveys*
- FIG Publication No. 56, Guidelines for the Planning, Execution and Management of Hydrographic Surveys in Ports and Harbors
- US Army Corps of Engineers, Manual No. 1110-2-1003, Engineering and Design – Hydrographic Surveying

6.3.3 Survey Coverage

The required coverage of a hydrographic survey will be dictated by the end-use of the data and by cost. There are two survey coverage options:

- Cross-section surveys, at a pre-defined spacing, normally carried out using a single-beam echo sounder (SBES). This method is most effective in shallow draft projects or in deep draft areas with relatively uniform sea-bed topography. Cross section surveys also provide a more rapid end-product and are typically the most economical procedure.
- Full-coverage surveys, using a multi-beam echo sounder (MBES), to achieve complete bottom coverage. MBESs can provide bottom coverage up to several times the depth of water and sufficient survey lines are run to ensure complete coverage. This method is typically used for deeper water projects where under-keel clearance is critical, for dredging maintenance and for investigation of underwater structures or obstructions. MBES surveys are more demanding and time consuming and therefore more expensive.

6.3.4 Survey Equipment

Survey equipment used during most surveys will fall into three main categories: depth measurement, position fixing and water level (tidal data). In addition, for MBES, the behavior of the survey vessel can be significant,

requiring the integration of motion sensor equipment. All equipment shall allow for continuous recording of survey information to suitable electronic data loggers.

6.3.4.1 Depth Measurement Equipment

Depths are usually measured using SBES or MBES equipment. These may be supplemented by side-scan sonar equipment to help detect smaller objects.

6.3.4.2 Single-Beam Echo Sounders (SBES)

To ensure that the equipment records the correct depths, the SBES must be calibrated, using a bar check procedure, before and after each segment of survey, or at a minimum on a daily basis, to correct for potential errors due to speed of sound in the water column and to set the correct depth of the SBES transducer. Similarly, a bar check must be carried out if any modifications are made to equipment or equipment mountings.

6.3.4.3 Multi-Beam Echo Sounders (MBES)

- MBES equipment shall be calibrated using a 'patch test' to determine:
  - The mount angles of the multi-beam transducer relative to the vessel's axes (roll, pitch and heading).
  - The latency (or time lag) between the MBES data and the position-fixing data.
- Good practice would also involve the use of a reference surface (i.e. an area of sea floor), where repeatable measurements can be made and compared, in order to identify systematic errors.

6.3.4.4 Motion Sensor Equipment

Motion sensor equipment (accelerometer) shall be used in conjunction with MBES measurements to improve the quality of sounding data, by correcting for variations in the vessel's pitch, roll and heading. As a lower-cost alternative, real-time kinematic (RTK) GPS or GNSS measurements can be used in correcting for vessel motion, although the resultant accuracy is limited by the GPS update rate.

6.3.4.5 Position-fixing Equipment

For most applications, the preferred method of horizontal control will be GPS or GNSS equipment in differential or RTK mode. In certain circumstances (e.g. if insufficient satellites are available or local conditions interfere with GPS reception), an auto-tracking total station instrument may be used.

6.3.4.6 Tide Gauge Equipment

Sea level measurements (i.e. water depth correlated to time of day) are needed in order to relate the hydrographic survey data to a defined vertical datum (chart datum). Typical methods for obtaining sea level information are:

- Automatic recording tide gauge (preferred option). This equipment must be regularly calibrated against a staff gauge to ensure its accuracy.
- Manual tide pole (or staff gauge). If this method is used, the frequency of measurement of the gauge must be such as to provide an adequate representation of the tide curve.
- Direct GPS RTK measurement of water level. If this method is used, then the GPS measurements shall be regularly correlated with conventional tide gauge measurements, to verify consistency.

6.3.5 Survey Procedures

6.3.5.1 Control

Survey control points and benchmarks will be installed, or existing control points utilized, in accordance with established procedures and relative to coordinate systems and datum outlined above.

6.3.5.2 Planning

The project survey specification shall address the density of bottom coverage required. This in turn will affect the choice of survey methodology to be adopted (i.e. cross section survey or full bottom coverage) and will determine survey line spacing. Planning will include direction of, and intervals between, cross sections. With MBES systems this will be affected by water depth and the cross-section spacing must allow for an overlap

of data, if full bottom coverage is required. Typically, for MBES surveys the equipment shall be restricted to obtain data up to 45° to 50° each side of the nadir. A minimum overlap of 20% is recommended between adjacent sections.

6.3.5.3 Tidal Measurements

Tidal measurements will be made continuously throughout the duration of the survey. If an existing tide gauge (automatic recording or manual observation) is available, then its height needs to be verified relative to the project survey datum. If not, then a tide gauge will be installed at a suitable location as close to the work area as possible. For complex tidal areas, multiple gauges may be appropriate. Automatically-recording tide gauges are recommended. If manual tide gauges are the only ones available, then careful consideration needs to be given to the frequency of recording, to ensure that the tidal curve is accurately determined. Regular monitoring of the tide gauge elevation is required to verify that outside factors are not affecting the measurements.

6.3.5.4 Positioning System

If possible, the on-board positioning system will be installed co-axial to the echo sounding transponder. If this is not practicable, a survey of the vessel shall be carried out to determine the relative locations of the positioning system, echo sounding transponder and any other data collecting equipment. The selected positioning system must be capable of continuous recording of the vessel's location. If MBES is used for soundings, then motion control equipment must be installed and recorded together with the sounding data.

6.3.5.5 Soundings

Soundings will be run in accordance with the planned cross section layout, there shall be an overlap of soundings between daily mobilizations.

6.3.5.6 Ancillary Survey Data

Specific projects may require additional types of survey data collection, not covered by this document, including:

- Side scan sonar surveys, used to create an image of the sea floor for detection of debris and obstructions
- Current measurements
- Sub-bottom profiling, used to indicate shallow structure of the seabed
- Magnetometer surveys, used in the detection of seafloor or sub-floor objects.

6.3.5.7 Additional Calibrations

In addition to the various equipment calibrations mentioned above, it is considered good practice to carry out the following checks, preferably on a daily basis:

- An independent static GPS check of the vessel's derived position, as determined by on board GPS or auto-tracking total station, relative to a control point on shore. This will provide a confidence level in the performance of the vessel's positioning system.
- A dynamic check against a distinctive bottom feature, for which a known location has previously been derived. This may reveal latent errors not apparent during the static check. Bottom features used for this purpose shall be located in relatively shallow water (less than 10m) to avoid a large echo sounder footprint and ensure that resolution of the target feature is commensurate with the positioning system being used.

6.3.5.8 Data Processing

- Survey data will be processed using approved software that combines soundings, positions, tidal data and motion sensor data.
- Processing will involve the preparation of a clean data set, which eliminates erroneous data, based on the various check measurements built into the survey, including elimination of any tidal data errors revealed by the practice of running survey check lines.
- Data sets from modern sounding equipment are very large and need to be carefully managed. Software packages are capable of smoothing the survey data, but this shall be avoided, unless the magnitude of the difference between 'raw' and 'smoothed' data is clearly identified.

- Processing software shall preserve data integrity and be capable of shoal bias thinning (i.e. the production of a 'thinned' data set that maintains the accuracy of the survey while reducing the amount of data that needs to be manipulated). This is especially applicable to SBES surveys.
- For survey data intended for the production of hydrographic charts, it is recommended that a Combined Uncertainty and Bathymetric Estimator (CUBE) surface is produced.
- For data intended for volumetric calculations, a grid of average depths will generally be required (a grid is not recommended for other uses, as it does not preserve actual sounding locations or depths).

6.3.5.9 Data Analysis

An assessment shall be made of the accuracy achieved during the hydrographic survey, to provide a confidence level in the charts, sounding sheets or other deliverables provided. The sources of all individual errors need to be derived from the various calibrations conducted during the survey, then statistically combined to derive the 'Total Propagated Uncertainty' (TPU) for the data set.

6.3.5.10 Deliverables

Deliverables will include paper copies and digital data.

- Paper deliverables will include charts, plans and a comprehensive survey report detailing methodology, results and accuracies.
- Digital data shall include point information for all soundings, together with located features and tidal data. Soundings shall be provided in ASCII format, using WGS84 latitude and longitude with depths below chart datum. Line information and point relating to survey features other than soundings shall be provided in an AutoCAD compatible format.

6.4 Construction Staking

6.4.1 Introduction

- This Section provides guidelines for performing construction staking and layout as required to establish horizontal and vertical positions of contract improvements.
- The responsible party for construction staking must be performed under the supervision of the surveyor.
- These guidelines for establishing lines, grades and construction stakes are minimum Standards; additional contractual requirements or tolerances may be shown on plans or included in special provisions for the work.

6.4.2 Pre-construction

6.4.2.1 Pre-construction Conference

- Prior to the commencement of construction activities, a meeting shall be held with the A/E, the entity's project manager, and surveying personnel. This meeting is of particular importance to the construction surveyor in order to plan and organize respective duties that conform to the Contractor's planned sequence of operations to avoid any unnecessary delays or inconveniences. The A/E will outline the working schedule and methods of operations and discuss construction details.
- The pre-construction meeting will determine who will authorize and control requests for survey and receive survey data and field notes.

6.4.2.2 Safety

- It is the Surveyor's responsibility to adopt the project health and safety plan and or provide an acceptable safety plan to ensure safety of survey crew.
- The survey crew will attend specific site safety orientations per project requirements.
- Each survey vehicle will have a first aid kit and working fire extinguisher.
- Each survey crew member will be outfitted and adhere to wearing the PPE (personal protection equipment) required by the Entity, EPC Contractor, A/E, or survey company, whichever is more stringent.

6.4.2.3 Survey Instrument Selection

- Conventional or GPS survey instruments or a combination thereof may be used to meet the tolerances outlined in this construction staking guidelines.
- Calibration certificates on applicable survey instruments will be made available prior to construction to ensure equipment is in good working order.
    - Levels will be checked for calibration using the two peg test; notes of the procedure will be provided prior to work. Levels shall be tested at weekly intervals and prior to layout of critical work.
- GPS shall not be used to establish positions for the following:
    - Structure layout horizontal or vertical positions.
    - Concrete pavement vertical positions.
    - Concrete curb, gutter and barrier vertical positions.

6.4.2.4 Pre-Construction Surveys

Pre-construction surveys incidental to construction staking may include but are not limited to:

- Location of existing survey control monuments and boundary markers for their referencing and perpetuation if disturbed by construction activities.
- Location of manholes or valves within construction areas to be adjusted to future grades.
- Verification of location and grade where new improvements tie into existing conditions.

6.4.2.5 Survey Control

- It is the responsibility of the surveyor to locate, verify, and document the accuracy of all existing control points before using them for construction staking control work. The surveyor must notify the A/E in writing of any discrepancies before using those points.
- The elevations, dimensions, and horizontal alignment of structures, earthwork, and roadways must be checked for plan errors, compatibility, and consistency with existing field conditions. If any discrepancy is discovered, the A/E must immediately be informed. New grades must be established from the approved plan with adjustments to match existing roadway features as approved by the A/E.
- The Surveyor will always consult with the A/E before doing any staking or computations. Data availability, project staging, or plan changes are all considerations that shall be discussed before starting initial layout.
- All field adjustments must be approved by the A/E. The surveyor shall always check with the A/E for changes to the approved plans before doing any staking or grade computations.
- Vertical Control and Bench Level Circuits (Benchmarks)
    - This activity consists of locating the existing benchmarks set during the preliminary phases of the project, verifying their accuracy, correcting errors if necessary, transferring benchmarks to new locations to prevent conflict with construction, and establishing new benchmarks as needed.
    - Additional benchmarks must be set so as not to conflict with the construction operations. They shall be set with a spacing not to exceed 150 m or other spacing required by the A/E.
    - Additional benchmarks must be of suitable material to endure the duration of construction.
    - Additional benchmarks shall be set in locations that will be convenient for future work. It is also beneficial to alternate on left and right sides of the roadway, particularly when work is to be done under traffic conditions.
    - Benchmark number and elevation shall be written on the guard stake or directly on the benchmark. All additional benchmarks set must be recorded (number or name, description, location and elevation) in the field book that is to be kept in the field office when not in use.
    - Good guidelines for locating benchmarks are:
        - At each end of large structures.
        - At points of change from cut to fill.
        - At high and low points.
        - Locations that are handy for cross sectioning of side hills.
        - Any time there is a difference of 8 m in elevation in rolling terrain.
    - Before starting a bench level circuit (bench loop), the level must be checked for accuracy. Along with peg testing the level (instrument), also check the tripod head and shoes and level rod tape and shoes for wear. If using a total station for setting benchmarks, ensure that the instrument is calibrated. This information shall be recorded in the field notes.

- In order to verify or establish elevations for benchmarks, they must be looped with a minimum of three benchmarks in the loop (two known).
- Minor errors in benchmark elevations shall be corrected in a manner that will not materially affect the work and brought to the attention of the A/E.
- Major errors or apparent discrepancies found affecting other benchmarks, existing plan information, and future work must be immediately brought to the attention of the A/E for correction or interpretation before proceeding with the work.

- Horizontal Control

  - Horizontal control begins with field-locating the control points, traverse points, section corners, etc., set by the original survey. These points will be noted on the plans along with field ties or can be obtained from the A/E. From these control points, the horizontal alignment for construction is established.
  - Additional control usually needs to be set outside the construction limits and there are special requirements for machine control grading projects. Consideration must be given to future use of these control points to prevent loss during the life of the project, provide for easy access, recovery, and inter-visibility.
  - Care shall be taken when establishing these reference points to assure their accuracy. When a control point is disturbed or destroyed, new monument for the point must be set and new coordinates established before any staking is accomplished in the area controlled by the disturbed or destroyed point. A new point number shall be used and the field notes shall be updated to note the disturbed or destroyed point, the new point, and their locations.
  - When the project is staked using coordinates, the staking must be performed using the project control coordinates found in the plan or provided by the A/E. Verify that the coordinates provided are correct by checking the units, datum, and coordinate system used on the project. Field crew shall verify coordinates by performing independent checks made from different control point set-ups. Consult with the A/E regarding the frequency and areas of the project that horizontal control needs to be maintained.
  - All additional control points established are to be documented in the field book with the point description, location, coordinates (ground values), and station/offset for use during the life of the construction project. They will be marked in the field for easy recovery. Crossed lath with fluorescent pink ribbon and the control point number legibly written is a standard practice.

6.4.2.6 Field Notes

Field notes are the written record of pertinent information, layout, measurements and observations of the project. They shall be kept according to uniform practices and conform, as a minimum, to the following general requirements:

- Neatness - Use a sharp pencil of at least 3-H hardness. Avoid crowding the information and keep the book as clean as possible.
- Legibility - Use standard symbols and abbreviations to keep notes compact. Use plain lettering to avoid confusion.
- Clarity - Plan work ahead so that data can be clearly indicated. Do not make ambiguous statements. Line up descriptions and make sketches for clarity. Record data in a consistent way. Assume that the person who will use your notes has no familiarity with the work.
- Completeness - Show all pertinent measurements and observations. Use a degree of accuracy consistent with the operation. If in doubt about the need for the data, record it. Review data before leaving the field. All entries must include:

  - The date and weather conditions.
  - Title of task.
  - Names of all persons in the survey crew and their assignments.
  - The title page must be completed as the book or project is started. The return address must be noted on the title page in case the book is lost. The book must be adequately indexed, pages numbered and cross-referenced to contents.

- Permanence - All entries shall be made directly into bound books. At the completion of the project, the books shall be filed as part of the permanent record in keeping with Project management document filing procedures

- Accuracy - Record exactly what was done at the time it was done rather than depending on memory at a later time. Never erase in a field book. If an item is incorrectly entered, draw a line through the item and insert the corrected value immediately above. When it is necessary to add data to notes previously prepared, the additional item shall be dated and initialed. Always enter notes directly into the record.
- Self-checking - Notes shall be kept so that the work can be checked without returning to the field. Any person familiar with the project shall be able to verify the accuracy of the work from the information contained in the notes.
- Electronic/digital field notes should be used when working with data collectors. The use of day files for electronic note keeping shall be used. The instrument number, party chief and crew members shall be input as electronic notes. The time stamp function shall be turned on at all times.

6.4.3 Construction

6.4.3.1 Original Ground Measures

Cross section measures of original ground shall be taken at each 20 m station as indicated on the Drawings. Intermediate stations shall be measured by cross section wherever grade breaks occur. Additional cross sections shall be taken at stations to include quantities measurement of retaining walls, drainage structures, etc. Elevation shots for original ground cross sections shall be taken at the centerline of construction according to the Drawings and as a minimum, at the following points perpendicular to and on each side of the centerline:

- grade breaks
- edge of pavement
- curb and gutter
- shoulder of road
- toe of slope
- centerline of ditch
- top of bank
- All other physical features within the project limits.
- In areas where overbreak or slides are anticipated, sections shall be extended out from centerline to include the anticipated disturbed ground area.

6.4.3.2 After Excavation Measures

Cross sections shall be taken at the same stations as the original ground cross sections. Elevation shall be for the bottom, sides and top of excavation at the following points on each side and perpendicular to the centerline:

- centerline
- grade breaks
- toe of excavation
- top edge of cut
- Original ground at a minimum of 3.0 m beyond the limits of excavation.

6.4.3.3 Slope Stakes

- Slope stakes shall be required for each cross-section station and at additional intervals such as points of curvature and tangency of curves, street intersections, vertical curve intermediate stations to include the high or low point of the curve, and at grade breaks. The stakes are to be set at points where the cut or fill slopes intersect the surface of original ground.
- Staking notes shall record the location of the slope stake in relation to the construction centerline, the existing elevation shot at the catch point, the planned elevation that the slope stake is identifying, what level of the design prism the catch point is identifying such as top of unclassified fill, top of sub-base, etc., the percent of slope for cut/fill, the distance to point slope staked, and the station of the slope stake.
- The information to be shown on a slope stake is as follows:
    - Distance from the catch point to the point being staked.
    - Percent of slope of the cut/fill.
    - Amount of cut/fill.
    - Stake’s location in reference to the centerline.
    - Centerline station of the slope stake written on the back of the stake.

- A reference stake shall be set for each slope stake. The reference stake shall be set a minimum of 3 m and a maximum of 5.0 m beyond the slope stake. The reference stake shall re-state the slope stake information in the event the slope stake is disturbed or destroyed. A hub shall be driven flush with the ground at the reference stake and all elevations and distances referenced to the hub.

6.4.3.4 Grade Stakes

- Cut or Fill Stakes
    - Vertical cut/fill stakes shall be used where the design prism does not contain sloped shoulders and ditches and a slope stake would not be needed. The cut/fill stake shall be comprised of a standard 13 mm steel stake driven flush with ground surface and accompanied by a site map with the following information written on it:
        - rebar number (#)
        - amount of cut or fill
        - distance to the point of cut/fill from the steel stake
        - description of the cut or filled type, i.e. subgrade, top classified
        - offset distance from construction centerline to the cut/fill point
        - centerline station of cut/fill point
        - elevation of the top of steel stake.
    - Cuts shall be given to the nearest 10 mm. Elevations of the top of hubs shall be given to the nearest 10 mm. Stakes shall be required at each 10 m station identified on the Drawings and at additional intervals such as points of curvature and tangency of curves, street intersections, vertical curve intermediate stations to include the high or low point of the curve, and at grade breaks. A record of the cut/fill, the design grade, the distance offset from centerline, the centerline station and the type of cut/fill being staked shall be written in the survey field book.
- Finish Grade
    - Grade hubs shall be set to verify that the road prism is at the correct elevation prior to the placement of leveling course material. Wooden hubs, painted or topped with colored whiskers, shall be set at the top of classified fill, within one hundredths of a meter tolerance (0.01 m). Stationing shall be 20 m on tangent and 10 m on curves unless the A/E approves otherwise. All grade breaks, vertical curve intermediate points to include the high/low point of the curve, PC and PT of horizontal curves, and street intersections shall be staked.
    - Hubs shall be established on the centerline of the road prism as a minimum where poured curb and gutter is incorporated into the designed road prism. Otherwise, hubs shall be established at the shoulder of the designed road prism, as well as the centerline of the road prism.
    - When parking aprons are staked, hubs shall be set on a 20 m grid pattern unless approved otherwise by the A/E. The field book shall contain the centerline station, the design finish grade elevation of the point staked, the elevation of the hub, and a description of the material being staked.

6.4.3.5 Drainage Facilities

- The location, type, size, length, and invert elevations for drainage facilities are given on the Drawings. Minor changes in locations and grades to meet existing field conditions may be made where necessary, but only with the approval of the A/E. If the planned design grade is found to be unworkable in the field, the A/E shall be notified immediately and all grade staking of the facility shall cease until further notice from the A/E.
- Storm Drains, Cleanouts, Outfalls, Catch Basins, Oil and Grease Separators, Manholes and Culverts A ground line profile shall be run directly above the centerline of the pipe and recorded in the field book before trenching occurs. The line and grade for storm drain pipe shall be given from reference hubs offset from each manhole, catch basin, angle point, outfall or cleanout. Reference hubs for culvert installation shall be offset from the pipe ends on the extended centerline of the culvert. One reference hub is required at each end of a culvert. Guard stakes shall be provided for each hub and shall identify the following information:
    - station
    - size, length and type of pipe
    - the amount of cut or fill from the top of the hub to the invert at the end of the pipe
    - The horizontal distance from the reference hub to the center of a manhole, cleanout, catch basin, angle point in a pipe, outfall or end of a culvert pipe.

- For each structure, the field book shall show the location, type, and size of the structure with a staking diagram showing all distances and pertinent elevations. Two (2) reference hubs shall be set for each manhole, cleanout, catch basin, angle point, and outfall. The reference hubs shall be offset no greater than 10 m from the facility they are referencing.
- Headwalls
  Headwalls for storm drains and culverts shall be staked by setting a hub accompanied by a guard stake on each side of the storm drain or culvert. The hubs shall be on line with the face of the headwall, or as directed by the A/E. An elevation shall be established on the hubs and written on the guard stake along with the offset distance to the center of the headwall.
- Dikes and Ditches
  Dikes/ditches shall be staked to the alignment, grade and slopes shown on the Drawings. Dikes/ditches shall be slope staked to the shoulder or flow line of the improvement with distances referenced to the improvement centerline. The criteria outlined under – Slope Stakes shall govern the establishment of slope stakes for this Work.
- Riprap and Slope Protection
  All rip rap and slope protection shall be staked as soon as possible after the pipe, fill, channel change or dike has been constructed. Slope stakes shall be set if needed.
- Curb and Gutter
  Reference stakes are typically set at even 10 m stations. All grade breaks, PVCs, PVTs, low points and high points on vertical curves shall also be staked. A hub and tack shall be set at an offset distance of one meter to the top back of curb. A lath will be set behind the hub and tack with the offset distance marked below the offset and the station marked on the back of the lath. The cut and fill will be to the top back-of-curb within 10 mm. All radius points at curb returns will be staked and additional stakes set breaking up the arc of the curve between curb returns. If valley gutters are to be built, they shall be staked and referenced.

6.4.3.6 Water Systems

- Pipe offset stakes are typically set at 20 m intervals with cuts to invert of pipe as indicated on the plans. Two offset hubs and lath shall be set for each tee, hydrant, water service, valve, or other water appurtenance, along with angle points and grade breaks in the alignment. The lath shall identify the feature being staked and state the elevation of the hub, the offset distance to the center of the feature, and the station of the feature as shown on the Drawings. The offsets shall be set at a reasonable distance to protect them from disturbance.
- An original ground line profile directly above the water line shall be run prior to excavation and recorded in the field book. The ground line profile refers to the elevation of the ground directly above the centerline of pipe and the grade line refers to the elevation of the bottom of pipe, except where otherwise noted. The field notes shall record the profile, the hub elevations, offset of the hubs, and the station of the feature being staked.

6.4.3.7 Sanitary Sewer Systems

- Pipe offset stakes are typically set at 10 m intervals with cuts to invert of pipe as indicated on the plans. A minimum of two reference hubs shall be set for each manhole, outfall or cleanout. Guard stakes shall be provided for each hub showing the information necessary to construct the facility. The minimum information to be shown on the reference stakes and in the field book is as follows:
  - Sewer alignment station of referenced point
  - Size and type of pipe
  - Cut or fill from the hub to the pipe invert
  - Offset distance from the hub to the centerline of pipe or center of the structure
- An original ground line profile directly above the sewer line shall be run prior to excavation and recorded in the field book. The ground line profile refers to the elevation of the ground directly above the centerline of pipe and the grade line refers to the elevation of the bottom of pipe, except where otherwise noted.
- The field notes shall record the profile, the hub elevations, offset of the hubs, and the station of the feature being staked.

6.4.3.8 Bridges

- Set stakes, nails, or other devices to control the location and elevation of the various parts of bridges and progressive phases of construction. Provide horizontal and vertical control for all elements of bridge construction. Stake drainage facilities, electrical conduits, water and sewer pipes, pedestrian and bicycle facilities, traffic signal and sign supports, illumination devices, and other items shown or identified that are to be integrated into the construction of the bridge.
- Bridge Survey Control Stations - Use the smallest number of original Project control stations as is practical for establishing positions and reference points for bridge construction on one bridge. Use of multiple control stations will increase the probability of incorporating error into the construction. Use control stations that are as closely related mathematically as practical. The Contractor may establish additional control stations as necessary to complete the survey work. Additional control stations shall be established in such a manner as to provide the accuracy needed to meet the required tolerances.
- Original Project control stations shall be used only after the following evaluation is completed for each bridge:
    - Supply a list of original Project horizontal and vertical control stations intended by the Contractor to be used in establishing positions on a given bridge.
    - Measure relative positions of original Project horizontal control stations intended to be used.
    - Measure elevation differences between original Project vertical control stations intended to be used.
    - Supply horizontal and vertical measurement data to the A/E.
    - Compare measured values with those computed from original horizontal network coordinates and vertical network elevations.
    - Any discrepancy of concern to either the A/E and/or the EPC Contractor will be resolved before that combination of control stations is used.

- Layout Marks and Reference Points - Substructure
    - Stake, reference, or otherwise identify locations, orientations, and elevations necessary for placement of substructure components, including but not limited to cofferdams, pilings (including batter), drilled shafts, footings, columns, abutments, caps, cross beams, bearing devices, temporary supports or falsework, and excavations and embankments associated with any of the above.
    - Verify and document the locations, elevations and spatial relationships with adjacent substructure components. On bridges where prefabricated beams will be used, measure and document span lengths between bearing devices at each beam location as soon as practical. Supply a copy of such documentation to the A/E for review before the next stage of construction.
    - Compute the final elevations after studying the plans, specifications, and shop drawings. Adjust the grades as needed to compensate for camber of prefabricated beams, chording of beams across the low side of superelevations, width of flat beams on superelevated surfaces, and any other factor resulting from design or construction methods.

- Layout Marks and Reference Points – Superstructure
    - Stake, reference or otherwise identify locations, orientations, and elevations necessary for placement of superstructure components including but not limited to beams, girders, diaphragms, earthquake restraints, deck, rails, structure mounted traffic control and illumination devices, and concrete forms, temporary supports and falsework associated with any of the above.
    - Stake alignment of structure as needed at each stage of construction. Stake alignment of poured-in-place items at 5 m stations or as established by the A/E. Stake alignment for the following items as needed to maintain the horizontal tolerance defined in this manual:
        - Outside edge of girder(s)
        - Face(s) or centerline(s) of internal girders or stem walls
        - Edge of deck
        - Alignment of grade breaks
        - Pedestrian and bicycle facilities
        - Rails and railings

- Stake grades at each stage of construction. Stake grade of poured-in-place items at 5 m stations, or as established by the A/E. Apply corrections to design grades based on the dynamics of the evolving structure. Corrections that may be required depend upon the design of the bridge and the construction methods employed. Provide correction values to the A/E at least 15 working days prior to incorporating into the structure. The following list is examples of possible corrections:
    - Design camber (upward adjustment to compensate for anticipated deflection)
    - Structural deflection (deflection of the bridge under its own increasing weight)
    - Post tensioning lift (upward movement of the bridge under post tensioning forces)
    - Structural shifting (dynamics of the bridge under eccentric loading).
    - Falsework deflection (deflection of falsework beams under increasing weight)
    - Falsework crush (compression of falsework supports under increasing weight)
    - Form crush (compression of forms under increasing weight)
    - Equipment deflection (deflection of deck finishing machine or deck rails)
    - Other adjustments to staked value to achieve the design grade

- Bridge Deck Grades - Set stakes or other devices to control the deck grade elevations. The exact process will depend upon the type of deck and the equipment being used.
- Portland Cement Concrete (PCC) Deck - The surveyor and survey crew leader shall attend the deck pre-placement conferences as required for each deck placement.
    - Control of a PCC deck may involve significant work with the deck placement crew to establish control for a deck finishing machine. Rails for supporting the deck finishing machine are generally set up on either side of the deck. Each rail is held up by adjustable supports every 1.5 meters. Adjust the rail at each support to the desired grade while the rail is supporting the weight of the finishing machine. Corrections may need to be applied as previously mentioned.

- Asphaltic Concrete (AC) Deck - Control of an AC deck will not generally involve as many variables as PCC. An AC deck serves as a wearing surface, but not a structural component. Asphaltic concrete will frequently be used as filler to create the desired superelevations when flat beams form the superstructure. Stake control of the finish grade like any asphalt finish grade. Under some circumstances, design camber and structural deflection may need to be considered.

6.4.3.9 Building Layout may include but not limited to:

- Provide finish floor benchmark.
- Staking for sub-basement rough grade
- Stake and grade building corners for pad excavation and construction. Provide finish pad grade stakes on pre-determined grid from A/E. As-built finish pad grades; provide to A/E for review.
- Provide offsets to building corners and gridlines along each edge of building.
- Provide offsets to centerline of building steel columns.
- Provide staking for, shear walls, retaining walls and elevator cores.
- Provide anchor bolt layout, check template layout, check post concrete pour anchor bolt locations; provide as-built comparison to plan locations within 1 week of footing being poured.
- Horizontal control lines for x and y axis for each floor
- Vertical control benchmark for each floor

6.4.3.10 Miscellaneous Construction

The A/E shall provide sufficient stakes for adequate control of all structures and incidental construction not specifically covered above. A staking diagram with respect to centerline and measurements for pay quantities shall be maintained in the field notes. Other items such as horizontal and vertical control shall be shown in the field book.

6.4.3.11 AMG (Automated Machine Guidance)

- Under the Construction Staking Subgrade bid item the surveyor may substitute global positioning system (GPS) machine guidance for conventional subgrade staking on all or part of the work. The A/E may require the surveyor to revert to conventional subgrade staking methods for all or part of the work at any point during construction if, in the A/E's and/or EPC Contractor's opinion, the GPS machine guidance is producing unacceptable results.

- No subgrade stakes are required for work completed using GPS machine guidance. Coordinate with the A/E throughout the course of construction to ensure that work performed using GPS machine guidance conforms to the contract tolerances and that the methods employed conform to the Contractor's GPS work plan and accepted industry Standards. Address GPS machine guidance issues at weekly progress meetings.
- GPS Work Plan - Submit a comprehensive written GPS work plan for department review at least 5 business days before the preconstruction conference. The A/E will review the plan to determine if it conforms to the contract. Construct the subgrade as the Contractor's GPS work plan provides. Update the plan as necessary during construction of the subgrade.
- The GPS work plan shall discuss how GPS machine guidance technology will be integrated into other technologies employed on the project. Include, but do not limit the contents to, the following:
    - Designate which portions of the contract will be done using GPS machine guidance and which portions will be done using conventional subgrade staking.
    - Describe the manufacturer, model, and software version of the GPS equipment.
    - Provide information on the qualifications of Contractor staff. Include formal training and field experience. Designate a single staff person as the primary contact for GPS technology issues.
    - Describe how project control is to be established. Include a list and map showing control points enveloping the site.
    - Describe site calibration procedures. Include a map of the control points used for site calibration and control points used to check the site calibration. Describe the site calibration and checking frequency as well as how the site calibration and checking information are to be documented.
    - Describe the A/E's quality control procedures. Describe procedures for checking, mechanical calibration, and maintenance of equipment. Include the frequency and type of checks performed to ensure that the constructed subgrade conforms to the contract plans.
- Equipment
    - Use GPS machine guidance equipment to meet the requirements of the contract.
    - Perform periodic sensor calibrations, checks for blade wear, and other routine adjustments as required to ensure that the final subgrade conforms to the contract plans.
- Geometric and Surface Information
    - Develop and maintain the initial design surface DTM for areas of the project employing GPS machine guidance. Confirm that the design surface DTM agrees with the contract plans.
    - Provide design surface DTM information to the department in LandXML or other A/E-approved format.
- Managing and Updating Information
    - Notify the department of any errors or discrepancies in department-provided information. The department will determine what revisions may be required. The department will revise the contract plans, if necessary, to address errors or discrepancies that the Contractor identifies. The department will provide the best available information related to those contract plan revisions.
    - Revise the design surface DTM as required to support construction operations and to reflect any contract plan revisions the department makes. Perform checks to confirm that the revised design surface DTM agrees with the contract plan revisions. Provide a copy of the resultant revised design surface DTM to the A/E in LandXML or other A/E-approved format. The department will pay for costs incurred to incorporate contract plan revisions as extra work.
- Site Calibration
    - Designate a set of control points, including a total of at least 6 horizontal and vertical points or 2 per km, whichever is greater, for site calibration for the portion of the project employing GPS machine guidance. Incorporate the department-provided control framework used for the original survey and design.
    - Calibrate the site by determining the parameters governing the transformation of GPS information into the project coordinate system. Use the full set of plan control points for the initial site calibration. Provide the resulting site calibration file to the A/E before beginning subgrade construction operations.
- Daily Calibration Checks

- In addition to the site calibration, perform site calibration checks. Perform these checks at individual control points not used in the initial site calibration. At a minimum, check the calibration at the start of each day as described in the A/E's GPS work plan. Report out-of-tolerance checks to the A/E. The measured position must match the established position at each individual control point within the following tolerances:
  - Horizontally to 30 mm or less.
  - Vertically to 20 mm or less.

b) Discuss the previous week's daily calibration check results at the weekly progress meeting for monitoring the GPS work.

6.4.4 Post - Construction, As-built Surveys and Record Drawings

As-built survey measurements shall be required for all constructed facilities and improvements to confirm the dimensions, lines, grades, locations, or materials as shown on the Drawings. Survey measurements shall be taken, field notes shall be kept, and accuracy shall be attained in accordance with this Division. As-built information shall be marked on a clean set of full-size paper copy Drawings and be submitted to the A/E at the completion of construction activity.

6.5 Utility Rights of Way

6.5.1 Introduction

This Subsection provides for the definition, use, and identification of Utility Rights-of-Way, existing or to be established for the project.

6.5.2 Definitions

6.5.2.1 Rights-of-Way

- The right to pass through the property owned by another.
- The strip of land subject to a non-owners right to pass through.
- Public right-of-way; the right of passage held by the public in general to travel on roads, freeways, and other thoroughfares.
  - A right-of-way may be established by contract, by long standing usage, or by public authority.
  - Also termed a public right-of-way (Refer to Black's Law Dictionary, Eighth Edition)

6.5.2.2 Easements

An interest in land owned by another, consisting in the right to use or control the land, or in an area above or below it, for a specific limited purpose.

- The primary recognized easements are
  - A right-of-way
  - A right of entry for any purpose relating to the dominant estate
  - A right to the support of land and buildings
  - A right of light and air
  - A right of water
  - A right to do some act that would otherwise amount to a nuisance
  - A right to place or keep something on the servient estate
- Also termed a private right-of-way
  Refer to Black's Law Dictionary

6.5.3 Establishing Rights-of-Way

6.5.3.1 Right-of-Way for Existing Utilities

To establish a right-of-way for an existing utility that is not within a right-of-way, the following shall be done:

- The existing utility shall be field surveyed to determine the location, course and/or depth of the utility.
- The field data shall be submitted to the A/E for confirmation and adherence to accuracy Standards. Once complete:

- the right-of-way width and length shall be determined;
- the right-of-way shall be added to the project drawings and/or to the Record Drawings and shall clearly state the purpose of the right-of-way;
- the ownership of the land affected by the utility shall be determined;
- the appropriate documentation shall be prepared to establish the right-of-way, showing the purpose of the right-of-way, the legal description of the right-of-way tied to the project control network, to whom the right-of-way is granted (grantee), and the ownership of the land (grantor);
- the necessary signatures and acknowledgements shall be affixed to the documents;
- the documents shall be recorded with the appropriate governmental agencies.

6.5.3.2 New Rights-of-Way

- The A/E shall determine the location, width, course, direction, depth and/or length of the new utility, using various criteria, which shall include but not be limited to:
  a) the purpose of the utility within the right-of-way
  - the depth or height of the utility
  - the terrain across which the utility will pass
  - the ownership of the land across which the utility will pass
  - design elements of the project which may obstruct the utility.
- The appropriate documentation shall be prepared to establish the right-of-way, showing the purpose of the right-of-way, the legal description of the right-of-way tied to the project control network, to whom the right-of-way is granted (grantee), and the ownership of the land (grantor).
- The necessary signatures and acknowledgements shall be affixed to the documents.
- The documents shall be recorded with the Entity.

6.5.4 Finalizing Rights-of-Way

Once the location of the rights-of-way are determined and established by document:

- Provide stakes and monuments in the field, per the specifications governing the type and construction of monuments, as determined by the A/E;
- Annotate the design drawings and/or the As-built drawings.

6.6 Digital Terrain Modeling (DTM)

In scientific literature, the terms Digital Terrain model (DTM), Digital Elevation Model (DEM) and Digital Surface Model (DSM) are not used. In most cases the term Digital Surface Model represents the earth's surface and includes all objects on it. Contrary to a DSM, the Digital Terrain Model (DTM) represents the bare ground surface without any objects like plants and buildings.

6.6.1 DTM Sources

- Existing Local DTM
  Check with entity for any available DTM's.
- Existing Global
  There are a few Global DTMs available for use, note that the accuracy is limited accuracy and the surface can be very poor in certain locations.

  Example: USGS GTOPO30.
- New Local job or site specific DTMs
  The local or job specific DTMs are collected locally as directed by the client, and can be as small as a single lot, or several hectares or kilometers in size.

6.6.2 Methods

Several methods are available for collecting a DTM, including the following:

- Lidar, Aerial photogrammetry, Radar

- Real Time Kinematic GPS, Total Stations, Scanning
- Topographic Maps
- Doppler Radar, Focus Variation, Range Imaging

6.6.3 Accuracy

- The accuracy of the DTM horizontally and vertically is affected by several factors, including but not limited to the following: Method, equipment, weather, personnel.
- When developing a DTM, qualified personal or subcontractors shall be used.
- Once the DTM surface is created it shall be checked in the Field for accuracy.

6.6.4 DTM Requirements for all Projects:

6.6.4.1 Less than 1.0 hectare or single lot developments

- Topographic survey shall be collected on all small lot developments to ensure accurate design tie in locations and quantities.
    - On small lot or parcels, it would be recommended to use a field survey crew to obtain the desired grid and critical points for use in a DTM for the site.

6.6.4.2 Large project sites

- The DTM requirements for a larger project will be dependent on whether it is a commercial site, larger residential or rural area.
    - Methods for the larger sites will be dependent on the required accuracy as required by the entity.

6.6.4.3 Quality Control

- All DTM's shall be checked for accuracy by taking ground field survey shots on a minimum of 10 percent of areas in the DTM. Critical point locations shall also be checked like curb tie-ins, driveways, building fronts, etc.
- Third party DTM's
    - If a DTM is provided from a third party or other sources, a 15 percent check shall be made to verify the accuracy of the provided DTM surface.

6.7 Surveys

6.7.1 Aerial Survey

6.7.1.1 Introduction –

Photogrammetric surveys establish targeted, and occasionally non-targeted, photo control on the ground to relate aerial photographs to a project's horizontal and vertical datums. The photo control is used by the Photogrammetrist to create topographic and planimetric maps for Design, Environmental, Traffic, Hydrology, Planning, and other functional units.

6.7.1.2 Field Surveys

- All photo control surveys shall be conducted in accordance with all of the pertinent requirements, and comply with the requested survey precision requested by the Photogrammetrist.
- All "pre-mark" photo control targets shall be in place before photography is acquired.
- It is recommended that all photo control surveys be completed before photography is acquired.

6.7.1.3 Placement of Photo Control

- Setting Photo Control Targets
    - Wherever possible, the photo control targets shall be set on pavement or other hard surfaces. The targets shall be painted with flat black and flat white paint. If it is not possible to set a target on a paved surface or other hard surface then a cloth target shall be set.

- When the location of the target is likely to be disturbed by vandalism, construction, agricultural or other activities, a durable reference monument shall be set and the target placed accurately on this mark.

- Photo Control Target Placement Tolerance
  - Each flight plan shall list a positional tolerance that limits the movement of the proposed photo control target from the flight plan location. This is especially important with respect to the wing points. Properly positioned wing points are critical to the aerotriangulation process. In general, the wing points may be moved parallel to the flight line, but shall avoid moving the wing points perpendicular to the flight line as the wing point may then fall outside the photography or too close to the middle of the photography, reducing the wing point's effectiveness.
  - Photo center (i.e. flight line) control monuments are established as close to the center of the flight line as possible. Their location and configuration is dependent upon the flight height. For highway work the closest to the flight line center that is most often achievable on the ground is on the shoulder of the highway. Whenever possible, primary control monuments that have been previously established on the ground by a primary control survey shall be used for all photo center control monuments. This allows the photo control survey to be horizontally and vertically referenced and tied directly to the primary control established on the ground as the framework for the survey control network without having to install additional monuments. This also greatly reduces the amount of field surveying needed to establish photo ground control since the primary control monuments need only to be targeted.
  - Photo wing control monuments are established at the extreme right or left outer edge of the flight line in the area of the overlapping photos. These points allow the control to be passed from one photo to another. Their location and configuration is dependent upon the flight height.
  - If the limits shown on the flight plan must be exceeded, A/E shall be contacted to determine the best location for alternate photo control.
- Photo Control Target Location Tips
  - The care exercised in targeting and positioning the photo control affects all subsequent photogrammetric processes and the final delivered products.
  - The planned location of the photo control provided with the flight plan will direct the general area where the targets are to be placed. Once in the general area, the positional tolerance given on the flight plan and the following tips shall be used to select the final target locations.
- Tips on selecting locations for the setting of photo control targets:
  - Use the flight plan to anticipate the position of the aircraft and avoid tall objects between the plane and the targets. Stand on the proposed target locations and imagine the plane traveling along the flight line while looking for obstructions.
  - Avoid tall objects that could obstruct the image of the target in one or more exposures. If there are unavoidable tall objects near a target then move the target within the tolerances indicated on the flight plan or set additional targets to ensure that the area will be properly controlled for the subsequent photogrammetric processes.
  - Avoid shaded areas. Visit the tentative target locations at the approximate time photography is to be obtained. Relocate the target to a sunny spot if there are shadows in the planned location. Set additional targets if needed.
  - Avoid overhead wires. It is difficult for the Photogrammetrist to measure the elevation of the photo control when there are wires suspended above the targets.
  - Remove grass from under cloth targets so that the growth of the grass doesn't distort the cloth target between the time it was set and the date of photography. Check the cloth target for "ballooning" caused by growing vegetation immediately prior to ordering photography.
  - Choose a level spot if available. A hard surface that will accept paint is ideal, as painted targets are more durable.
- Tips on the orientation of the photo control targets:
  - When possible, photo control targets shall be placed so that the legs are aligned perpendicular and parallel to the flight line.
  - When photo control targets must be placed on a steep slope, the target shall be oriented so that two of the legs that form a straight line lie along the slope at approximately the same elevation.

6.7.1.4 Target Specifications

- Where the white targets are similar in color or do not contrast with the underlying surface they shall be outlined with flat black paint or black roofing paper or similar material to create contrast and aid in identifying it on the aerial photograph.

- Painted targets may be used on local or private roads where permission has been granted from the appropriate authority or owners.
- Due care must be taken to ensure that materials used for targets will not damage the environment or cause any harm to humans, animals or machinery. Plastic targets must not be used in livestock areas.
- All mapping control target material and fastenings (i.e. pins, wire, nails etc.) must be removed from the field as soon as possible after the aerial photography has been captured to minimize the impact on property owners. However, preplanned control points (but not target material) may be retained in urban areas if they are suitable for future works.

6.7.1.5 Accuracy Requirements

All photo control horizontal and vertical surveys shall meet the positional accuracy as specified by the Photogrammetrist.

6.7.1.6 Airborne GPS Surveys

- It is the responsibility of the Aerial Mapping Contractor to:
  - Coordinate the use of the Airborne GPS Surveys (ABGPS) for the project.
  - Coordinate the schedule of the ABGPS project.
  - Coordinate the required target control layout, dimensions and accuracy specifications.
  - Coordinate the placement of check points to be targeted on the control scheme for the project.
- It is the responsibility of the Land Surveyor to:
  - Set and survey, if needed, the monuments for the base stations.
  - Ensure that the provisions of this appendix are met when performing ABGPS surveys.
  - Facilitate communication during the flight.
- ABGPS Control Requirements
  - The Land Surveyor shall perform the ABGPS field survey to the following requirements:
  - The base stations horizontal coordinates shall be produced control monuments established by Primary Control Survey procedures.
  - The photo control horizontal coordinates shall be produced from control monuments established by Primary or Secondary Control Survey procedures.
- Base Station Location Requirements
  The base station locations shall be based upon the following criteria:
  - One Station within 1 km of the Airport to be used for a static initialization of the airplane GPS equipment.
  - One Station within 1 km of each end of the project.
  - Additional Stations a maximum of 40 km spacing throughout the project.
  - GPS suitability.
- Equipment Requirements
  - Base-Station Equipment Requirements - Surveys shall provide the following equipment for use at each base-station location:
    - A dual frequency GPS or GNSS Receiver
    - A data logger capable of logging data at 2 hertz or better and that has adequate memory for logging data for up to 6 hours.
    - A Geodetic Antenna.
    - Batteries sufficient to power the GPS or GNSS equipment for up to 6 hours.
    - A fixed height tripod.
  - Airborne Equipment Requirements - The following equipment is required for use in the aircraft:
    - A dual frequency GPS or GNSS receiver.
    - A data logger capable of logging data at 2 hertz or better and that has adequate memory for logging data for up to 6 hours.
    - An event marker.
    - Batteries sufficient to power the GPS or GNSS equipment for up to 6 hours.
    - All necessary cables and adaptors.
- Aircraft Equipment Setup
  - The Land Surveyor shall approve the aircraft antenna and camera system prior to use on an ABGPS project. The aerial photography Contractor shall provide the Land Surveyor with the GPS or GNSS antenna specifications and offset survey data.

- The Land Surveyor and Aerial Photography Contractor shall coordinate the following connections per the aircraft specific checklist provided by the Engineer:
  - Connect GPS receiver to the GPS antenna data only splitter port, the data collector, the event marker, and the battery.
  - Connect the event marker to the camera.
  - If the receiver has a built-in event marker then the Land Surveyor and Aerial Photography Contractor shall make a direct connection between the camera and the appropriate port or jack on the GPS or GNSS receiver.

- Pre-flight Check
  The Land Surveyor and Aerial Photography Contractor shall verify the following for the aircraft GPS or GNSS equipment:
  - Sufficient battery power for the ABGPS project.
  - The GPS or GNSS satellite configuration and the reception of all signals.
  - The activation of the camera shutter causes events to be logged in the GPS or GNSS receiver.
- Pre-flight Static initialization
  The Land Surveyor shall collect GPS or GNSS data for 20 minutes prior to the flying of the project for a preflight static initialization and again verify that the activation of the camera shutter causes events to be logged. Also, they shall note the camera event number and the GPS or GNSS receiver event number.
- ABGPS Flight
  The aerial photography Contractor shall fly the flight paths shown on the approved flight plan. Each flight line will be flown twice to minimize the risk of having to repeat the project due to image errors or loss of GPS or GNSS signal lock.
- Post-Flight Check
  The Land Surveyor and Aerial Photography Contractor shall verify that the camera events were logged in the GPS or GNSS receiver after the ABGPS flight. If there is a discrepancy in the number of photographs taken compared to the number of events logged, the discrepancy shall be noted.
- Post-Flight Static Initialization
  The Land Surveyor shall continue to collect GPS or GNSS data for an additional 20 minutes after the ABGPS flight for a post-flight static initialization.
- Deliverable data
  - ABGPS Receiver Data
  - Base-station Receiver Data
  - Ground Control Data
  - Mapping Epoch Coordinates
  - Mission Epoch Coordinates
- Post-mission GPS or GNSS Processing and Data Analysis
  The Land Surveyor will post process the kinematic data and confer with the A/E for the results of the GPS or GNSS processing.

6.7.2 Satellite Survey

6.7.2.1 Definition

Satellite surveying is a form of surveying and mapping that uses information derived from various satellite constellations, together referred to as GNSS (Global Navigation Satellite System), consisting of the U.S. Global Positioning System (GPS), the Russian GLONASS, the European Union's Galileo and the Chinese BeiDou systems, to provide spatial location on or above the surface of the earth.

6.7.2.2 GNSS Standards and Specifications

- GPS at: https://www.ngs.noaa.gov/PUBS_LIB/GeomGeod.pdf
- GLONASS at: http://www.nis-glonass.ru/
- Galileo at: http://www.esa.int/Our_Activities/Navigation/The_future_-_Galileo/Galileo_satellites
- BeiDou at: http://www.beidou.gov.cn/

6.7.3 Bathymetric Surveys

6.7.3.1 Introduction

Bathymetric surveys may include, but not be limited to:

- Surveys of original ground or sea bed in water depths between approximately one (1) meter to thirty (30) meters.
- Surveys and as-built mapping of dredged channels.
- Monitoring of siltation.
- Locations and elevations of underwater structures or objects.

All work will conform to the general requirements for hydrographic surveys required above.

- All survey work will be related to the WGS84 or UTM, as directed.
- For safety considerations, all work will be carried out during daylight hours, unless otherwise permitted.
- An assessment must be carried out regarding prevailing water and weather conditions, before embarking on any water-based survey work.

6.7.3.2 Survey Procedures

- For surveys in up to 1 meter of water depth, conventional survey techniques can be applied, providing that safe water and underfoot conditions apply.
    - Horizontal position and elevation will be obtained simultaneously by total station measurements from known control points or by differential or RTK (Real-Time Kinematic) GPS or GNSS positioning.
    - Survey data shall be recorded in a dedicated data logger, in real time.
    - To ensure full coverage of the required area, it is recommended that cross sections are carried out at a pre-determined spacing (minimum 25 meters).
    - Survey points will be plotted and depth contours (isobaths) interpolated at agreed vertical intervals (typically 0.5 meters for most applications, reduced to 0.25 meters for more critical areas).
    - Existing sea bed conditions and approximate depth of silt shall be recorded.
    - There will be no requirement to record tidal data, although approximate water level at the time of survey shall be noted.
- For surveys in depths of 1 meter or more, survey equipment and personnel will need to be located on a floating platform or boat, entailing the following requirements for horizontal positioning, soundings, tidal data and motion control:
    - Horizontal position by total station measurements from known control points:
        - Horizontal position by total station will be restricted to close inshore work
        - For total station measurements, the point of measurement must be coaxial with the echo-sounder transponder, to enable simultaneous recording of horizontal and vertical measurements.
        - Both total station measurements and soundings must be accurately time-related in order to combine horizontal positions with observed depths.
    - Horizontal position by GPS or GNSS measurements:
        - Wherever practicable, in order to reconcile horizontal and vertical measurements the GPS equipment and echo-sounder transponder shall be installed co-axially.
        - If co-axial mounting is not possible, then a minimum of two GPS receivers shall be installed and spaced in such a way as to provide a strong geometric relationship with the transponder location.
        - Pre-survey determination of the relative locations of GPS receivers and transponder on the vessel will be required during each installation of the equipment.
        - GPS observations shall be continuously recorded (preferred 10Hz).

        - An independent daily check of the on-board GPS receiver shall be carried out using a separate GPS receiver or total station, to verify performance of the vessel's position-fixing system.
        - Regular dynamic checks of the GPS shall also be made against a distinctive and permanent site feature (preferably in water of less than 10-meter depth).
    - Depth measurement using Single-Beam Echo Sounders (SBES):
        - SBES equipment will typically be used in situations where full sea-bed coverage is not required.
        - Soundings will be obtained in the form of cross sections, at a pre-determined spacing.
            - For depths less than 10 meters, the maximum spacing of cross sections shall be the lesser of 3x average depth or 25 meters.
            - For depths between 10 meters and 30 meters, the maximum spacing of cross sections shall be 50 meters.
        - Equipment must be calibrated using a standard 'bar check' routine.
        - Bar checks must be carried out before and after each survey mission, or, at a minimum, on a daily basis.
        - The echo sounder must be accurately positioned relative to the position-fixing equipment.
    - Depth measurement using Multi-Beam Echo Sounders (MBES)
        - MBES equipment will typically be used when full sea bed coverage is required.
        - MBES coverage shall be limited to between 45° and 50° each side of the nadir.
        - MBES cross sections shall be spaced to provide at least 20% overlap, to ensure full sea bed coverage.
        - Equipment must be calibrated using a Patch Test, to determine the mount angles of the transducer(s) relative to the vessel's axes (roll, pitch and heading).
        - Wherever practicable, the equipment shall be tested using a reference surface (i.e. a suitable area of sea floor that has been previously surveyed), where repeated measurements can be compared in order to identify systematic errors.
        - For optimum results, motion sensor equipment shall be used to correct for variations in pitch, roll and heading of the vessel (otherwise the GPS measurements can fulfil this purpose, but accuracy may be compromised due to the GPS update rate).
    - Tidal Measurements
        - All surveys carried out within tidal areas must be corrected for tidal variation.
        - Unless otherwise agreed, a continuously recording tide gauge must be used for all bathymetric surveys.
        - The tide gauge must be situated so as to provide representative tidal information for the survey area.
        - The elevation of the tide gauge must be verified relative to the project datum.
        - In the event that an automatically-recording tide gauge is unavailable, a manual tide gauge will be installed. Manual recording of tidal data must be of sufficient frequency to accurately depict the tidal curve.

6.7.3.3 Survey Accuracies

- For engineering surveys or for shallow water harbors, berths and associated critical channels, with minimum under-keel clearances:
    - Soundings - 1 meter horizontal and 0.15 meters vertical
    - Features - 0.5 meters for both horizontal and vertical
- For non-shallow water harbors, berths and associated critical channels, with minimum under-keel clearances:
    - Soundings - 2 meters horizontal and 0.25 meters vertical.
    - Features - 1 meter for both horizontal and vertical
- Areas shallower than 100 meters where under-keel clearance is less critical but features of concern to shipping may exist:
    - Soundings - 5 meters (+5% of depth) horizontal and 0.5 meters vertical.
    - Features - 2 meters for both horizontal and vertical
- Areas shallower than 100 meters where under-keel clearance is not considered to be an issue:
    - Soundings - 5 meters (+5% of depth) horizontal and 0.5 meters vertical
    - Features - Not applicable

6.7.3.4 Survey Processing

- Survey data processing will combine soundings, positions, tidal data and motion sensor data, into a single data set.
- A clean data set will be required, eliminating any erroneous data revealed by the various check measurements.
    - Data smoothing will not be acceptable, without prior agreement. Data smoothing, if agreed, must clearly identify the magnitude of discrepancies between raw and smoothed data.
    - Large data sets may be thinned using 'shoal bias thinning', provided the accuracy of the survey data is maintained.
    - For data that will be used for chart preparation, a Combined Uncertainty and Bathymetric Estimator (CUBE) surface will be provided.
    - For volumetric calculations a data set comprising a grid of average depths will be required (grid spacing to be agreed on a project by project basis).

- A survey report will be required, including the following:
    - Discussion of the methods used for the survey
    - Analysis of the results, with an assessment of accuracies achieved
    - Identification and quantification of all potential error sources, with derivation of the Total Propagated Uncertainty (TPU) for the data set.

6.7.3.5 Deliverables

- Hard copies of all plans and charts
- Daily logs and reports
- Evidence of equipment calibrations
- Digital files including all soundings, located features and tidal data

6.7.4 Geodetic Control Surveys

6.7.4.1 Geodetic Control survey

- Accuracy of Geodetic Control Surveys
  http://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-networks.htm
- As required, the A/E will obtain data on various stations of the National Geodetic Network established by the Kingdom of Saudi Arabia, as per Ain El Abd coordinate system or as established by Entitiy (Important note: A/E shall obtain written approval from Entity for project specific adopted coordinate system).
- The Consultant will establish, maintain, and expand as per project specifications where necessary, the Geodetic Horizontal Controls and the Precise Vertical Control as required by the entity.
- Monuments shall be placed at all corners, angle points and at approximately 100 m intervals on tangents along these boundaries.

6.7.5 Primary, Secondary, and Tertiary Control Surveys

6.7.5.1 Primary Control Surveys

- Primary Control Surveys are used to establish the initial Control for:
    - The Boundaries of Sections and Districts
    - Airports Primary and Secondary Control (PAC, SAC)
- Survey shall be used within Community Area to locate the boundaries of Districts that are developed. The boundaries shall be established and monumented on each corner (on land only), and all angle points along the boundary
- Within Community Area, Airport Area and New Industrial Area all section boundaries shall be established and monumented at each corner, along the boundary lines (on land only), using primary order surveying.
- All monuments established by primary order surveying shall have elevations established using Precise Leveling accuracy methods.

6.7.5.2 Secondary Control Surveys

- Secondary Control Surveys are to establish:
  - Intersections of Street Centerlines
- Survey shall be used for further subdivision of Sections and Districts. Within Community Area, all sector boundaries, street centerlines and intersections shall be established and monumented, as well as block boundaries, using secondary order surveying..
- Secondary order surveying shall be used for further subdivision of Existing development Area, Airport Area and New development Area. A minimum of two monuments shall be established within each development site. All other Districts, including Support and Secondary Industries, shall have each block monumented, with coordinates established for each point.
- Each point, so established, shall have an elevation established in accordance with Primary Leveling criteria.

6.7.5.3 Tertiary Horizontal Control Surveys

- Tertiary horizontal Control Survey are to establish:
  - Lot Lines
  - Construction Surveys
  - Local Project Control, etc.
- Survey shall be used for the final subdivision of blocks into lots, plots or parcels for final usage. This covers all lot or plot boundaries within Community Area which shall be established and monumented.
- All the entity facilities (i.e., pump stations, storage reservoirs, rest areas, O & M Centers, etc.) shall have their boundaries established and monumented.

6.7.5.4 Accuracy Requirements

- Standards and Specifications for Geodetic Control Networks
  http://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-networks.htm

6.7.6 Precise, Primary and Secondary Vertical Control Surveys

- Benchmarks shall be installed where required as per the project specifications.
- Benchmarks shall be established using differential leveling methods.
- The order of accuracy shall be as required by the entity per project specifications.
- Geodetic Leveling Class and Accuracy Standards and Methods:
  http://www.ngs.noaa.gov/FGCS/tech_pub/Fgcsvert.v41.specs.pdf
- Monuments shall be set and constructed in accordance with the latest revision of drawings as approved by the Entity.

6.7.6.1 Equipment (Digital and Conventional Levels)

- Use per manufacturer's specifications.
- Use all levels with methods as referenced above.

6.7.7 Cadastral Control Surveys

6.7.7.1 Introduction

Cadastral surveying is that branch of surveying which is concerned with the survey and demarcation of land for the purpose of defining parcels of land for registration in a land registry.

- Every cadastral control survey shall be carried out in strict compliance with these guidelines.
- Before commencing a cadastral control survey, existing survey data relating to the survey is to be obtained by consulting the records of Entity.

6.7.7.2 Cadastral Project Control

A network or series of control points that are established per procedures. The Cadastral Project Control is adjusted independently of other cadastral measurements.

- Standards for the Positional Accuracy of Cadastral Surveys When Using Global Navigation Satellite Systems (GNSS), February 23, 2009, Cadastral Survey, Bureau of Land Management, Department of the Interior, Washington, DC
- Geo Information in the Kingdom of Saudi Arabia, Ministry of Municipal and Rural Affairs, Kingdom of Saudi Arabia, 2010
- Modernization of Saudi Cadastre Alrajhi, M., and Hawarey, M. Ministry of Municipal and Rural Affairs, Riyadh, Saudi Arabia
- Boundary and Surveys Maps Act, Chapter 25, 02/07/2007, Singapore Attorney General's Chambers
- Cadastral Survey Guidelines, Government of South Australia, July 2014

6.7.8 Cadastral Lot Surveys

6.7.8.1 Survey Evidence

- A surveyor must, before carrying out a cadastral survey, obtain all information that is likely to provide evidence of the boundaries of land to be surveyed; and that is reasonably accessible.
- A surveyor must, in carrying out a cadastral survey, locate all existing survey marks, reference marks, improvements and natural features likely to provide evidence of the boundaries of the land; and connect the survey to all existing surveys of land in the vicinity likely to provide evidence of the boundaries of land by:
    - Connecting to at least 2 apparently sound survey marks or reference marks placed or accepted in the existing survey; or
    - If there are not 2 apparently sound survey marks or reference marks to which the survey may be connected - by connecting to such apparently sound survey marks as are available and to improvements in a manner that enables the existing survey to be re-established.
- If significant differences in the data from an existing survey are revealed then perform further work as may be necessary to establish whether or not the difference results from an error in measurement in the existing survey, the placement or acceptance of the survey mark in the existing survey or the siting of the improvement.

6.7.8.2 Marking of Boundaries

- The boundaries in a cadastral survey must be marked with acceptable monuments together with any additional markings as are necessary to assist in locating the corners and the direction of boundaries.
- The line identification and marking must be implemented in a manner so that the defined boundary can be readily identified.

6.7.8.3 Survey Boundaries

The cadastral survey must relate to the boundaries referred to in the documents of title of the subject land and adjoining parcels of land.

6.7.8.4 Field Requirements of a Cadastral Survey

- A datum must be adopted and verified in accordance with a previous cadastral survey or plan.
- If an abstract of field records is to be lodged, bring the bearing and co-ordinate datum on to the datum as called for in Cadastral Control Surveys.
- If a connection is shown on the document of title, measure that connection unless the position of the subject land can be satisfactorily determined otherwise.
- Connect the cadastral survey to relevant permanent marks, primary cadastral marks and other relevant survey marks.

- Locate and clearly describe any feature on or near the boundaries of the subject land likely to affect those boundaries.
- Locate and clearly describe any feature within the subject land the description and position of which is necessary for the purpose of the survey.
- Determine the length and bearing of each surveyed boundary of the subject land and independently check the accuracy of each determination.
- Ensure that an irregular boundary is determined at all conspicuous changes in direction at such intervals as are necessary to accurately determine the boundary.
- If the survey of a subdivision is connected to a minimum of two permanent marks or primary cadastral marks and one reference mark in situations where they are unlikely to be disturbed, the placement of any further permanent or primary cadastral marks within the subdivision may be postponed if the construction of roads or buildings or other works are to be undertaken which are likely to displace those permanent marks or primary cadastral marks during construction.
- If the placement of further marks is postponed a supplementary abstract of field records showing the particulars and connections to the marks placed must be lodged within one month after completion of construction.

6.7.8.5 Information to be recorded in the field records:

- The recording of cadastral survey information gathered in the field is undertaken in a systematic manner and is readily comprehensible; and information in the field records includes:
    - A list identifying the survey instruments used and their calibrations.
    - All measurements made in the field and all corrections applied.
    - Sufficient information to prepare an abstract of field records.
    - All field records are kept so as to be readily available for submission.

- The information to be recorded schematically on an abstract of field records of a cadastral survey provides:
    - Clear details of the cadastral survey datum and relationship to the property boundaries.
    - The method of marking the perimeter boundaries of the property under survey.
    - Any relevant information external to the property under survey which has aided in the determination of property boundaries and the relationship with existing and new survey marks.

- The information to be recorded on cadastral survey plan provides:
    - That a plan of survey is prepared using conventional signs and symbols as accepted by the controlling jurisdiction.
    - The plan clearly portrays all relevant information which relates to the property boundaries, road alignments and any registered easements or reservations or conditions in the nature of an easement which relate to the land under survey.

- Reports to accompany an abstract of field records or survey plan may include:
    - The relevant facts concerning abuttals and encumbrances, existing occupation details, relationship with other relevant cadastral surveys and the manner in which the boundaries of the property under survey have been determined.
    - Provide details on the date of calibration of measuring equipment used in the cadastral survey.
    - The appropriate marking out or definition of the roads, reserves, boundaries, lots and common property has been made.
    - The connection of the survey to permanent marks, primary cadastral marks and reference marks as required or postponed in accordance with Subsection 6.7.9.
        - Survey (Cadastral surveys) Regulations, SR No. 56/2005, Version April 18 2008, National Mapping Council of Australia

6.7.9 As-Built and Topographic Surveys

As-built, topographic, spot height and contour surveys shall be carried out using accepted horizontal and vertical survey control as described. Automated data capture methods shall be used and final maps also presented in a format compatible to entity systems and software.

6.7.9.1 Planimetric Mapping Information

The absolute paper plan position of any well-defined point of detail shall be correct to within ± 0.3 mm RMSE (Root Mean Square Error) at the plan scale, when checked from the nearest control station.

6.7.9.2 Height Information

- Ground survey spot levels on hard surfaces shall be correct to ± 10 mm RMSE and elsewhere to ± 50 mm, except on ploughed or otherwise broken surfaces in relation to the nearest control station.
- Height information shall be provided:
    - either as an elevation to depict details true to ground,
    - or as spot heights throughout the survey area,
    - or as height of detail, i.e. from ground terrain to top level of the details, e.g. height of a lamp post.
- Elevations shall be surveyed such that the ground terrain of a feature which attached or intersected with the ground is derived. Thus, when using reflectorless Total Station, correct location(s) of detail point(s) must be surveyed to feature from the ground terrain. For instance, the base of a street lamp pole shall be surveyed instead of random point on the pole.
- Generally, spot heights shall be taken at intervals of not more than 15 m to allow capturing of possible discontinuities of terrain. Spot heights shall be taken on all roads, at intersections, building corners, edges of carriageways, invert of drains, footpaths, bridges, fire hydrants, other salient ground features and at all changes in grade.

6.7.9.3 Level of details to be surveyed

- All visible details shall be surveyed. Where relevant, indicate features that are considered encroachments. If encroachment survey is to be carried out, it shall be done according to cadastral survey Standards.
- Saplings and trees where required shall be surveyed and described. Generally, trees with girth 300 mm and above (measured 1 m above ground level) are surveyed.
- List of features to be located and shown:
    - Property and right-of-way monuments
    - Visible boundary features, e.g. walls, fences, hedges
    - Roads, tracks, footways, paths
    - Buildings and ancillary facilities and structures
    - Utility structures and above-ground evidence of underground utility lines
    - Landscape and vegetation
    - Water features
    - Earthworks
    - Railway features
    - For sewer manholes, electrical manholes and inspection chambers, the cover levels and invert levels shall be surveyed if accessible. The type of manhole and inspection chamber, pipe or conduit size and material, and direction of flow shall be reflected in the plan.
    - For drains, invert levels and coping/top levels shall be surveyed generally at 20 m interval. For cascading drain, the coping and invert levels shall be surveyed. Covered drains with iron grating shall be surveyed. pipe size and material, and direction of flow shall be reflected in the plan.
    - Above-ground electric boxes, lamp/cable posts with numbers, exposed/overhead cables, etc. shall be surveyed.
- Cross-sections must be right-angle to center line and shall be surveyed generally at 30 m interval and 15 m along curves, tunnels roads etc.
- Road names and building/block numbers shall be noted in the field and shown on the map.
- Edges of ponds, lakes, streams, or other water bodies shall be surveyed.

6.7.10 Verifying Surveys by Others

All Consultants working for the entity shall perform check surveys on the following types of surveys:

- All previous surveys for the entity
- All adjoining surveys
- Other Survey Consulting Contractors working on the same projects
- Roadway construction, drainage, utilities, airports, power lines, airports, railroads, pipelines, right-of-way and property boundaries, and other surveys common to construction and mapping.

6.7.10.1 Survey Verification as follows:

- Minimum of 3 horizontal control points.
- Minimum of 2 vertical control points.
- On adjoining lots, at a minimum check property corners on coincident property lines
- On topography, construction, mapping, etc., at a minimum check tie in points, outfalls, flowlines, angle points etc., to ensure your survey or the previous surveys all match together and are using the same datums.

6.7.11 Monitoring Large Area Subsidence

6.7.11.1 Introduction

A network of subsidence benchmarks has been established for the purpose of detecting any land movement.

- Monitoring will include vertical measurements only.
- Measurement of Subsidence Using GPS/GNSS
- For initial detection of significant movements, static GPS/GNSS observations will be used, including all existing subsidence benchmarks.
- Repeat measurements will be made at agreed intervals.
- A minimum of three (3) remote benchmarks will be identified or established, situated on bed rock not liable to subsidence. These ‘controlling’ benchmarks will be incorporated into the measurements, to enable detection of ground movement within the area of interest.
- Results will be tabulated (and graphed, if required), including apparent differential movement between monitoring epochs.
- GPS/GNSS measurements are not as accurate as conventional leveling; therefore any significant movement trends identified through the GPS/GNSS data will be verified by leveling.

6.7.11.2 Conventional Leveling Measurements

- Depending upon results from GPS/GNSS measurements, a determination will be made as to whether a full- or partial- leveling regime will be required for the subsidence benchmarks.
- Monitoring shall be carried out using primary leveling procedures.
- A proposed program of leveling observations will be developed based on the existing network and focused on any apparent movements.
- Subsequent monitoring visits will follow the same measurement protocol, to enable direct comparisons between monitoring epochs.
- The benchmark network data will be processed using an approved ‘least squares’ adjustment process.

Results of each monitoring visit will be tabulated.

6.7.12 Monitoring Horizontal and Vertical Movement of Structures

6.7.12.1 Introduction

Monitoring of horizontal and vertical movement of structures may include but is not limited to:

- Mosques and minarets
- Seawater cooling canal slabs (above and below water)
- Control gates, pipes and pump houses
- Bridges and towers
- Tanks (elevated and ground)
- Industrial facilities and equipment
- Public buildings.

All monitoring carried out under this item will use first-order procedures and equipment.

- Precise leveling procedures will comply with requirements.
- Primary horizontal control procedures will comply with requirements.
- Frequency of monitoring will be determined by the client on a case-by-case basis.

6.7.12.2 Survey Reference Monuments

- Survey monuments used for monitoring measurement must be of stable and durable construction. Some examples are as follows:
  a) Cast-in-place concrete pile with #16 diameter steel bolt (standard survey fitting).
  b) Steel pile driven to refusal with #16 diameter steel bolt.
  c) Steel bolt set into bed rock or existing stable concrete structure.
- Whenever possible, the survey monument shall allow for forced-centering of survey equipment. If not possible, and tripod-mounted equipment is needed, then fixed-leg tripods shall be utilized.
- Survey reference monuments must be located so as to provide a strong geometric figure, consistent with optimization of measurements.
- Unless site constraints dictate otherwise, each survey monitoring point shall be visible from at least two reference monuments.
- Local reference monuments, established to monitor a specific location, must be related back to remote control points that are unlikely to be affected by local movement.

6.7.12.3 Survey Monitoring Points

- Points used for monitoring measurement need to be fixed, stable and capable of being used for repeat measurements over a lengthy period of time. Different types of points may need to be used and care needs to be taken to minimize impact to the structure. Some examples are as follows:
  - Survey prisms, directly attached to the structure.
  - Flat survey targets, epoxied onto the surface of the structure (only use in non-sensitive areas).
  - Bolts drilled into the structure (capable of being occupied by a level rod).
  - Fixed and well-defined points on the structure that can be reliably re-measured.

6.7.12.4 Horizontal Monitoring

- Control Network Measurement
  - Measurements required to establish the reference control network will be carried out in accordance with primary control procedures.
  - All possible cross measurements between reference points will be obtained, in order to strengthen the network.
  - Wherever possible, external reference objects will be included in the control observations, to provide a gross check on the stability of the control network.
  - The control network data will be processed using an approved ‘least squares’ adjustment protocol.
- Monitoring Measurement
  - All normal precautions will be observed to ensure that measurements comply with first-order survey procedures.
  - During each monitoring visit, care shall be taken to use the same base station – reference station combination for each set of measurements.

- Measurements shall be commenced at approximately the same time of day and carried out in the same sequence, to minimize external influences.
- Wherever possible, redundant measurements shall be made to monitoring points from different points in the control network.
- Measurements to individual points can be angle and distance, intersecting angles or intersecting distances, depending on circumstances. Reflectorless instruments may be used over short distances, providing the accuracy requirements stated herein are complied with. However, the same combination of measurements shall be maintained throughout the whole life-cycle of the monitoring.
- Results of each monitoring visit will be tabulated and compared to the base value from the initial visit. Differential movement will be tabulated and graphed, if significant.

6.7.12.5 Vertical Monitoring

- Control Network Measurement
  - Measurements required to establish the reference control network will be carried out in accordance with precise leveling procedures.
  - A remote benchmark must be established in an area unlikely to be affected by local movement.
  - All possible cross measurements between reference points will be obtained, in order to strengthen the network.
  - The control network data will be processed using an approved ‘least squares’ adjustment protocol.

- Monitoring Measurement
  - All normal precautions will be observed to ensure that measurements comply with first-order leveling procedures.
  - Measurements shall be commenced at approximately the same time of day and carried out in the same sequence, to minimize external influences.

6.7.13 Monitoring and Evaluating Ground Water Elevations and Data

6.7.13.1 Introduction

There is a need to sample ground water and monitor water elevations at certain pumping wells and piezometer locations, to ensure that:

- Groundwater quantities can be effectively managed.
- Groundwater quality is maintained.
- Ground subsidence can be minimized.

6.7.13.2 Monitoring Control

- Benchmarks will be established at each well site, to use as a basis for ground water elevation monitoring.
- Benchmarks will consist of survey markers drilled into the concrete pad around the well (if existing) or a punch mark on an accessible part of the well assembly.
- Benchmarks and piezometers will be connected to existing primary control; using secondary leveling techniques.
- Ground elevation adjacent to the well head or piezometer will be measured.
- Horizontal location will be established.
- A report will be compiled to include coordinates and elevations of benchmarks and piezometers, with descriptions including photographs.

6.7.13.3 Ground Water Monitoring

- Ground water elevation monitoring at well sites will be effected by direct measurement between the well casing and pump column using a metal tape or lead line (shallow wells) or electrical well-sounding equipment. Elevations will be related to the well head benchmark.
- Piezometer measurements will be recorded by a data logger or portable readout unit.
- Results will be provided in the form of a spreadsheet, including comparisons between successive monitoring visits and incorporating the following information:

    - Name and location of well or piezometer
    - Date of measurement
    - Reference point to which measurements are related
    - Ground surface elevation, depth to groundwater and elevation of groundwater surface

6.7.14 New Witness Posts

Witness posts shall be set at all primary control points as follows:

- All primary construction control points
    - Horizontal
    - Vertical
- Airports
    - All PACs (primary airport control)
    - All SACs (secondary airport control)
    - All witness post locations set on airports must be pre-approved by the airport manager prior to setting.
- Cadastral Corners
    - All baseline points and corners

6.7.14.1 Type of Posts

- Metal post with Metal Sign
- Fiberglass post

6.7.15 Fundamental Benchmark

Benchmarks shall be constructed in accordance with the entity's standard drawings and all subsequent revisions thereto. Installation, cleaning, priming, and painting of the proper witness posts and monument shall be included.

A diagram shall be prepared for each permanent benchmark showing clearly its general location, with dimensions to at least three easily recognizable and durable reference points, together with its description and designation.

3 Digital photographs of the benchmark shall be taken as follows:

- One (1) of the elevation mark, from a position that clearly shows the station markings.
- Two (2) of the benchmark structure, from 3 to 10 meters away and from two different locations, showing the general location and surrounding features.
- The elevation of the benchmark shall be measured in accordance with the precise vertical control survey standards.
- Photographs shall be annotated and submitted with the elevation report.

6.7.16 Geodetic Control Pillar

- Geodetic Control Pillars shall be constructed in accordance with entity specifications and all subsequent revisions.
- They shall be constructed of the highest quality materials and workmanship to assure longevity and durability.
- They shall be placed so as to be stable and protected from nearby activities whenever and wherever possible.
- Number and location of monuments shall be as directed by Entity.

6.7.17 Second and Third Order Control Monuments

- Second and third order control monuments shall be constructed in accordance with Entity specifications and all subsequent revisions.
- They shall be constructed of the highest quality materials and workmanship to assure longevity and durability.
- They shall be placed so as to be as stable as possible and protected from nearby activities.
- They shall be placed in locations with good visibility in all directions and intervisible with a minimum of two other control monuments, and/or as directed by the Entity.
- They shall be completed with aluminum bronze plaques and witness posts.

6.7.18 First, Second, and Third Order Control Plaques

- Plaques shall be constructed in accordance with entity specifications and all subsequent revisions.
- The plaques shall be stamped or otherwise marked with all pertinent information.

6.7.19 Boundary Marker

- Boundary Markers shall be constructed in accordance with entity specifications and all subsequent revisions.
- They shall be placed so as to mark the boundary lines and corners as directed.
- They shall be placed so as to be as stable as possible and protected from nearby activities.
-

6.7.20 Bronze Cadastral Survey Plaque

- The bronze cadastral survey plaques shall be constructed in accordance with entity specifications and all subsequent revisions.
- They shall be stamped or otherwise marked with all pertinent information.

6.7.21 Lot Monuments

- The lot monuments shall be constructed in accordance with entity specifications and all subsequent revisions.
- Shall be placed at all lot corners and/or along the lot lines as directed by the entity

6.7.22 Underwater Surveys

6.7.22.1 Introduction

Underwater Surveys may be required for inspection of existing facilities or conditions, including but not limited to, the following:

- Natural sea-bed materials, dredged channels, prepared gravel beds, rock or concrete slope protection and the like.
- Cooling system structures, moorings, foundations, piles, sheet pile walls, intake and outlet structures, pipelines, retaining structures and other structural elements.
- Navigational equipment, buoys, hulls of barges and other vessels.

The purpose of such underwater surveys will be to provide information pertaining to damage, corrosion, effectiveness of repairs, functionality of equipment and evaluation of future maintenance requirements, and to facilitate an assessment of whether work performed by others has been carried out in accordance with designs and specifications.

- The surveys will generally be limited to depths of up to thirty (30) meters.
- Surveys in water depths of up to one (1) meter will be carried out by conventional survey techniques.
- Underwater surveys below 1 meter depth will be carried out by teams of qualified divers, who shall include a qualified engineer. Appropriate certifications of competence will be required.
- Underwater inspections will be carried out to one of three levels of detail, as determined by the A/E.

- Level 1: General Visual Inspection
  - Confirm as-built structural plans
  - Detect obvious major damage or deterioration due to overstress (e.g. collisions), severe corrosion or extensive biological attack.
  - This level of inspection is generally regarded as an overview, used to develop a subsequent inspection strategy, and shall reveal the following:
    - Steel - extensive corrosion or severe mechanical damage.
    - Concrete - Major failures, spalling and cracking, severe reinforcement corrosion.
- Level 2: Close-Up Visual Inspection
  - A complete detailed inspection of selected components or critical areas of structures.
  - Identification of damaged or deteriorating areas hidden by surface biofouling.
  - Limited measurements of deteriorating areas (may be preceded by cleaning), using measuring scales or calipers.
  - Limited probing or testing for structural integrity.
  - This level of inspection shall reveal typical defects such as:
    - Steel - moderate mechanical damage, major corrosion pitting.
    - Concrete - surface cracking and crumbling, rust staining, exposed rebar or other reinforcing material
    - Wood - External damage due to marine borers or pre-damage infestation, splintered wood, loss of bolts or fasteners.
- Level 3: Highly Detailed Inspection
  - Level 3 inspections will only be carried out by qualified engineering and testing personnel.
  - This level is designed to provide data pursuant to a structural assessment. Procedures, including non-destructive testing, will be used to detect hidden or imminent damage, loss in cross-sectional area and material homogeneity.
  - Prior cleaning will normally be required.
  - Partially destructive testing (e.g. sample coring) may be required.
  - This level of inspection shall reveal the following information or defects:
    - Steel - remaining thickness of material
    - Concrete - location of rebar, extent of rebar corrosion, internal voids, changes in material strength
    - Wood - Internal voids and damage due to marine borers, changes in material strength

6.7.22.2 Frequency of Inspection

The frequency of inspection will vary, depending on the expected rate of damage and deterioration. Active areas (e.g. ships' berthing areas) are likely to deteriorate more quickly.

Recommended frequencies, per US Navy, 'Volume 4 NAVFAC MO-322, Inspection of Shore Facilities' are as follows:

- Superstructure, piling and sheet piling above the water line - annually
- Concrete/steel members at splash/tidal zones and downwards - at least every 6 years
- In areas where marine infestation is known to be a problem, these frequencies will be reduced accordingly.

6.7.22.3 Documentation

- Documentation must be comprehensive and provide a full understanding of location and condition of the various elements inspected.
- Pre-planning shall include a scheme for designating structural elements or other key items, for subsequent reference throughout the survey.
- Documentation shall include daily logs of inspection findings, including measurement data, locations of observations and water depth.
- Wherever practicable, inspections shall be documented with photography and/or video, referenced and labeled with the description and location of the object. A slate, with reference information shall be included in each photograph or video.