Guideline Part B
for Underground Utilities (UU) As-built Surveys

TECHNICAL SPECIFICATIONS FOR SURVEY WORKS FOR UNDERGROUND UTILITIES INFORMATION SYSTEM (UUIS)

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ABBREVIATION

Abbreviation	Definition
3D	3-Dimensional
AT	Aerotriangulation
CADept	Civil Aviation Department
CP	Check Points
EML	Electromagnetic Locating
GCP	Ground Control Points
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPR	Ground Penetrating Radar
GSD	Ground Sampling Distance
HK 1980 Grid	Hong Kong 1980 Grid System
HKPD	Hong Kong Principal Datum
LandsD	Lands Department
PCL	Pipe Cable Locating
RGB	Red-Green-Blue
RTK	Real-time Kinematic
SMO	Survey & Mapping Office
UAV	Unmanned Aerial Vehicle
UU	Underground Utilities
UUIS	Underground Utilities Information System
WDs	Work Departments

1 INTRODUCTION

1.1 Background

1.1.1 Every year the vast majority of seemingly routine street excavations occurring around the territory are adversely impacted by the lack of usable information about buried utility infrastructure. A project can be delayed for days and weeks because extra time is needed to figure out where utilities are buried so the works can be planned and performed without undue risk. A large-scale construction project can be stalled for months, incurring delay claims and variation orders that significantly increase costs, because the locations of utility installations were not properly recorded or depicted and were later found obstructing planned foundation and drainage works. What these kinds of risks and delay in works projects have in common is that they all can be prevented if accurate, comprehensive underground utility information is available for rapid integration and analysis in the planning and design stage.

1.1.2 According to the Chief Executive's 2021 Policy Address, a new initiative of 3-Dimensional (3D) Digital Underground Utilities Database was introduced to promote an accurate 3D digital underground utilities database with a view to facilitating the construction industry to plan and conduct the underground works efficiently and reducing road closure time resulting from the excavation works, thereby benefiting the community as a whole.

1.2 Underground Utilities Information System (UUIS)

1.2.1 The Audit Report 70 Chapter 4 recommended Government to explore the development of an effective management and control system over underground space occupation. An essential first step toward the said recommendation involves developing geo-enabled utility data models and IT system for enabling data interoperability and integration. The essential foundation allows geo-enabled data to be created, shared, and integrated seamlessly for many different domains and applications. Highways Department engaged an IT contractor to develop a prototype to prove the concept of such system, and Highways Department's IT contractor has submitted the final report for the prototype of the Utility Management Information System by the end of 2020. Riding on the prototype, Lands Department (LandsD) takes forward of developing the 3D Digital Underground Utilities Database, also known as the Underground Utilities Information System (UUIS).

1.2.2 The UUIS is a 3D digital database with underground utility data contributed by participating Work Departments (WDs) and private Underground Utilities (UU) stakeholders or acquired by LandsD/ LandsD's employed term contractors. The database aims to provide a common platform for participating WDs and private UU stakeholders to contribute and share UU data; for the construction industry to plan and conduct the underground works efficiently as well as reducing road closure time arisen from excavation works. The database is initially shared with participated WDs and private UU stakeholders and their corresponding consultants and contractors on a need-to-know basis. Sharing of the data will be extended to the other stakeholders including telecommunication stakeholders at appropriate stage.

2 SURVEY DATUM AND GENERAL WORKFLOW

2.1 Survey Datum

2.1.1 Unless otherwise specified, all horizontal coordinates of the survey data shall be referenced to and expressed in the Hong Kong 1980 Grid System (HK 1980 Grid).

2.1.2 Unless otherwise specified, all vertical levels of the survey data shall be referenced to and expressed in the Hong Kong Principal Datum (HKPD), which is the height datum generally used in Hong Kong and referred through the bench marks of LandsD.

2.2 Site Reconnaissance

2.2.1 A site visit usually will be conducted to familiarise with the site condition and checking the availability of survey controls in project / survey vicinity, so as to work out the appropriate surveying method and allocation of resources.

2.3 Calibration of Equipment

2.3.1 Prior to the field survey, all survey equipment deployed to the survey work shall be calibrated. This is to ensure that the equipment is in good condition and functioned properly to achieve the required accuracy. The calibration certificates shall be available for inspection upon request by the Government Representative.

2.4 Establishment of Survey Control

2.4.1 The "Geodetic Survey Station" [1] and/ or "Survey & Mapping Office (SMO)'s land boundary survey station" [2] and/ or "Global Navigation Satellite System (GNSS) Real-time Kinematic (RTK) Control Station" [3] preferably are adopted for the origin of survey controls.

[1] The "Geodetic Survey Station" is a trigonometric station, a traverse station or a GNSS control station or bench mark emplaced and mathematically fixed under the Hong Kong Geodetic Survey System with coordinates and levels published by the Geodetic Survey Section, SMO, Lands Department.

[2] The "SMO's land boundary survey station" is a survey mark over which survey observations are made in connection with land boundary surveys carried out by the SMO, Lands Department. It can be a "geodetic survey station" or a survey station established by SMO in the previous land boundary survey.

[3] The "GNSS RTK Control Station" is a control station established in accordance with paragraph 3.5 of this part.

2.4.2 Terrestrial survey method, such as Triangulation, Trilateration, Traversing or GNSS survey method, or integrated method should be employed for establishment of the horizontal control stations with reference to the HK 1980 Grid depending on sites conditions and the project requirements.

2.4.3 Horizontal control stations are required to be evenly distributed within and near the locations of sites and should be placed at locations not vulnerable to disturbance as far as practical. Sufficient working space should be made available around each control station to enable necessary instrument to be erected and operated.

2.4.4 For establishing vertical control stations, survey methods include ordinary / direct levelling, trigonometrical heighting or height or GNSS. Vertical control stations are referenced to the HKPD.

2.4.5 All survey control stations, either horizontal or vertical control stations, should be verified and checked before use. Details for respective survey methods for establishment of survey controls are described in Section 3.

2.5 Data Capture / Collection for Underground Utility

2.5.1 The data of the underground utilities should be accurately captured in the vicinity according to the accuracy standard stipulated in this technical specification.

2.5.2 Data collector is recommended to adopt one of the survey methodologies stated in this technical specification, as described in Section 4 to 8, to capture raw data of the features, including

(i) Laser Scanning Survey;

(ii) Photogrammetric Survey by Unmanned Aerial Vehicle;

(iii) Pipe Cable Locating / Electromagnetic Locating Survey;

(iv) Ground Penetrating Radar Survey; and

(v) Close Range Photogrammetric Survey.

2.6 Data Processing

2.6.1 The raw data captured shall be processed and checked against the quality.

2.6.2 Deliverables shall be provided by the end of the UU Survey, including but not limited to 3D point cloud, survey drawing, Geographic Information System (GIS) data and survey report. The requirements are stipulated in Section 10. The survey report shall be certified by the Professional Land Surveyor[4], which the survey is carried out either by himself/ herself or under his/her immediate direction and supervision.

[4] A professional land surveyor refers to a Corporate Member of the Hong Kong Institute of Surveyor (Land Surveying Division), or a Registered Professional Surveyor (Land Surveying) under Cap. 417.

3 ESTABLISHMENT OF SURVEY CONTROL

3.1 Practice

3.1.1 Considering the nature of the underground utilities survey and the required accuracy of the surveyed utilities, the following accuracy standard of establishing control stations shall be adopted with reference to the latest version of the *Accuracy Standards of the Control Survey* published by the LandsD.

Survey Method	**Class**[5]
Horizontal Control established by Terrestrial Survey Method	H3 to H6
Vertical Control established by Terrestrial Survey Method	V3 to V6
Horizontal Control established by GNSS	GH3 to GH5
Vertical Control established by GNSS	VH3 to VH5

3.2 Traversing

3.2.1 Whenever traversing method is employed for establishment of the horizontal control stations, the traverse should be started from and closed onto known stations which are acceptable to the Government Representative or origins which must be a "Geodetic Survey Station" or "SMO's Land Boundary Survey Station".

3.2.2 Before any traverse begins, the reliability of the survey stations used for an origin should be checked. Position of the origins can be checked by observing angles and distances to at least two known stations with an included angle and at least one distance measured.

(i) Survey tolerances – Bearing / angular measurements:

Distance	**Tolerance**
Under 15 m	±2' 00"
15 m to 150 m	±1' 00"
Over 150 m	±0' 30"

(ii) Survey tolerances – Distance measurements:

Tolerance: ± (0.015 + 0.0001 x distance in metres) metre

3.2.3 Angular measurements should be taken with a 6-seconds total station or instruments with better precision, and a minimum of one arc of observation on both faces, Face-Left and Face-Right, should be made.

3.2.4 Distances should be measured to 0.001 m and all necessary corrections, such as prism correction, should be applied.

[5] With reference to the Accuracy Standards of Control Survey (Version 2.0) published in September 2010, the class refers to different accuracy standard for survey control establishment requirement.

3.2.5 When a traverse longer than 1.5 km is run, control bearings should be observed reciprocally between traverse survey stations and some other geodetic survey stations, at such station intervals as will adequately control the orientation of the traverse lines. The number of traverse survey stations between control bearings should not be more than 15. In special circumstances where there is no practical alternative, the use of a single ray observed to a distant geodetic survey station to control the orientation of the traverse lines can be adopted with justification.

3.2.6 Self-closed and/or unclosed traverse is NOT allowed.

3.2.7 Allowable misclosure should be mathematically adjusted. Either Least Square Adjustment or Bowditch Rule could be adopted. References to the latest version of the Engineering Survey Practice Guides for Works Projects published by Land and Engineering Survey Board or the Accuracy Standards of Control Survey published by the LandsD could be made for relevant survey requirement. In general, for engineering survey and utilities survey,

(i) Allowable angular misclosure of traverse should not exceed ($20\sqrt{n}$) seconds, where 'n' is the number of traverse stations.

(ii) Allowable linear misclosure of traverse should not exceed (10+2S/15) mm, where 'S' is the total length of the traverse in metres.

3.3 Direct / Ordinary Levelling

3.3.1 Two-peg test shall be conducted prior to the commencement of the levelling survey. The collimation error shall not exceed 3 millimetre per 30 metre.

3.3.2 Height of survey control marks should be determined by direct levelling connected to at least two consecutive bench marks established by the Lands Department. The maximum height differences of the measured value and the computed value shall not exceed ($12\sqrt{k}$) mm, where k is the distance in kilometre between the two points being considered.

3.3.3 Equal distances for the Foresight and Backsight of a setup is preferably maintained.

3.3.4 Self-closed / close loop levelling is NOT allowed except justification is provided.

3.4 Trigonometrical Heighting / Height Traversing

3.4.1 This method is usually carried out together with traversing.

3.4.2 Measure the height of instrument and target at each setup.

3.4.3 Observe the forward and backward vertical angles from the instrument to targets in both Face-Left and Face-Right positions. Reciprocal height observation can be performed to improve the accuracy of height determination.

3.4.4 The allowable misclosure of a height traversing is ($10 + 10\ \sqrt{n}$) mm, where n is the number of traverse legs involved.

3.4.5 Station heights are then deduced by computing the mean delta height differences and instrument heights and then error is mathematically adjusted along the traverse.

3.5 GNSS RTK Positioning

3.5.1 RTK method by GNSS can be applied to establish survey controls for the utilities field survey.

3.5.2 The distances between new RTK control stations and known control stations should be kept as long as possible, preferably over 30 m.

3.5.3 RTK system check should be performed before and after the survey. Observation and acceptance criteria are described in the following paragraphs.

3.5.4 Observation Criteria:

(i) Observation time: at least 2 minutes with epoch rate of 1 second (i.e. 120 epoch)

(ii) Number of observation session for each new station: 2 or more

(iii) Interval between observation sessions > 10 minutes

(iv) Position quality value ≦ 0.02 m

(v) Height quality value ≦ 0.03 m

(vi) Elevation mask ≧ 15°

3.5.5 For each observation session, the averaged RTK coordinates would be accepted if the averaged position quality and height quality values fit the above criteria. Data cleaning can be used to filter out the poor observations epoch by epoch within each session. However, excessive data cleaning should be avoided and it is recommended no more than 50% of the observed epoch should be discarded.

3.5.6 The discrepancy of the repeated RTK coordinates should be less than 0.03m in horizontal (individual component: Northing & Easting) or 0.001 second (Latitude / Longitude) and 0.10 m (Ellipsoidal Height / HKPD) in vertical.

3.5.7 Independent check

(i) The angles, distances and height differences derived from RTK control stations should be checked against the terrestrial survey method.

(ii) The discrepancies are accepted if they are within the survey tolerance below:

Measurement	**Tolerance**
(i) Bearing / Angle	± 3’ 00” for distance under 30 m ± 2’ 00” for distance over 30 m
(ii) Distance	± 0.05 m
(iii) Height Difference	± 0.10 m

(iii) In addition, if any nearby old stations and trigonometric stations can be observed from the new RTK control stations, the distances/ bearings between them should be measured for independent check and the tolerance as stated above should be referred for the checking.

3.5.8 The RTK control stations should not be used for further breakdown of survey controls.

4 LASER SCANNING SURVEY

4.1 General

4.1.1 Laser scanning survey is a contact-free measuring technique which effectively collects high density point cloud of ground features. It is useful in capturing UU features with open trench for delivering the location, size and shape, and able to convert the raw data to different formats. Geo-referenced point cloud data, survey drawings and GIS data shall be the deliverables of the survey.

4.1.2 Laser scanning survey shall be adopted to confirm and record the location and other attribute data of the exposed target utilities within the survey area. It is considered as Survey Type A in PAS 128 Underground utility detection, verification and location specification. The quality level achieved should be documented as QL-A.

4.2 Accuracy

4.2.1 Laser scanning survey should be performed in dry condition with the following accuracy requirements.

PAS128 Quality Level	Criteria	Accuracy of the Point Cloud data	Supporting Data
QL-A	Horizontal accuracy	± 50 mm	Horizontal and vertical location of the top, bottom or centreline of the utility.
	Vertical accuracy	± 50 mm	
	Relative levels of pipe inverts within the chamber	± 15 mm	
	Pipe sizes	± 15 mm	
	Box culverts	± 20 mm	

4.2.2 The position and optimum number of tie-points and control point for each scan shall be planned in order to carry out registration. Tie-points or control points shall be distributed at the extent of the survey area to provide better geometry for registration. The registration error should be within ± 50 mm. The point cloud data should be checked with check points or 3 tie measurements with the tolerance as below:

Check point	
Northing	± 50 mm
Easting	± 50 mm
Height	± 50 mm
Tie measurement	
Difference	± 50 mm

4.2.3 Registration of multiple scans is constrained by tie-point/ tie-point or point cloud / point cloud method. Minimum 3 tie-points are required if only tie / tie registration is conducted; minimum 40% overlapping is required if only cloud/ cloud registration is used.

4.2.4 The 3D positions of all check points should be surveyed by survey method such as radiations from a known control stations by total station and geo-referenced to the HK 1980 Grid.

4.3 Equipment Specifications

4.3.1 The scanner should capture the point cloud data which providing the intensity values and Red-Green-Blue (RGB) colour values.

4.3.2 The equipment should be able to collect a set of 3D point cloud for a panoramic field of view (320° horizontal and 360° vertical).

4.3.3 The equipment should use a Near-Infra-Red or Infra-Red laser (e.g. 830 nm or 1550 nm), supported with an eye-safe, short-range scanning capability (e.g. < 100 m) and a minimum range of approximately 0.6 m or a range recommended by the manufacturer.

4.3.4 The scan resolution, such as the scan frequency and pulse repetition frequency, should be configured thus a minimum point spacing of 10 mm can be achieved.

4.3.5 The laser scanner and other equipment related to Laser Scanning Survey should be calibrated by agreed intervals recommended by the Professional Land Surveyor.

4.3.6 The range accuracy should be < 10 mm over a distance of 25 m. The laser point density should be 300,000 points per second or better.

4.4 Survey Procedures

4.4.1 The survey should be conducted by using the most suitable system to meet the requirement of the task in terms of efficiency, safety and survey accuracy, and to comply with all relevant legal requirements. The scanning should not be operated in raining conditions. The following steps are recommended before conducting the survey in manholes/ horizontal pipes/ culverts and open trench:

(i) The operator should prepare an equipment checklist to check for all equipment used.

(ii) Survey control stations should be established at locations in accordance with Section 3. GNSS or Traversing may be adopted as the survey method for establishing the control network.

(iii) If the targets do not have known coordinates, 3 pairs of well-defined points should be scanned for checking. The distance discrepancy should be less than 50 mm.

(iv) Conduct a trial run of the scanner on the ground so that data is properly collected without any mechanical problems.

(v) Ensure the surveyed object is located within the range limit of the scanner and start the survey. The scanner should be placed on both sides along the target utility to avoid uneven point cloud distribution.

(vi) Make sure the quality and completeness of the collected data in 3D point cloud by visualising the point cloud on-site using a cell phone or a tablet computer.

(vii) Ground verification survey should be conducted at each survey location to obtain checkpoint data for comparing with the scanning data for quality control purpose.

4.5 Survey Deliverables

4.5.1 Deliverables, including but not limited to field notes, computation sheets / data, raw and processed data, survey drawings, GIS data and survey report, in respect of the survey should be entered to the computation folder and certified by Professional Land Surveyor. The requirements are stipulated in Section 10.

5 PHOTOGRAMMETRIC SURVEY BY UNMANNED AERIAL VEHICLE

5.1 General

5.1.1 An Unmanned Aerial Vehicle (UAV) is used as a survey equipment to capture data such as photographs, videos and point cloud of ground features for engineering and development works. From collected data, a photogrammetry software can create geo-referenced orthomosaics, elevation models or 3D models of the project area. These models can also be used to extract information such as highly-accurate distances measurements. Deliverables of the survey shall include by not limited to Geo-referenced point cloud data, survey drawings and GIS data.

5.1.2 For inaccessible area that the Terrestrial Laser Scanning cannot cover, aerial photographs captured by UAV could be used to produce 3D colourised point cloud to complement the inaccessible area.

5.1.3 The government enacted the Small Unmanned Aircraft Order (Cap. 448G), which was commenced on 1 June 2022. All photogrammetric survey conducted by UAV, such as qualification requirements and operating procedures, shall be strictly adhered to the Order.

5.2 Accuracy

5.2.1 The photogrammetric survey should provide 3D point cloud data as one of the deliverables. The accuracy of this data must be checked and ensured to meet the acceptable tolerance specified in this section. In order to maintain accuracy, it is important to determine the appropriate camera and flying height for defining the ground sampling distance (GSD). Before the aerotriangulation (AT) process, ground control points (GCP) should be digitised. Independent check points (CP) should be used to verify the accuracy of the data.

5.2.2 Horizontal Accuracy Standard

Required Accuracy XY (cm) σ	Allowable GCP Error (cm) 1/4σ	Allowable CP Error (cm) 1/3σ	Allowable AT Error (cm) 1/2σ	Recommended GSD (cm) 1/2σ- 1σ
5	1.3	1.7	2.5	2.5 - 5.0

5.2.3 Vertical Accuracy Standard

Required Accuracy Z (cm) σ	Allowable GCP Error (cm) 1/4σ	Allowable CP Error (cm) 1/3σ	Allowable AT Error (cm) 1/2σ
5	1.3	1.7	2.5

5.3 Personnel Responsibilities

5.3.1 An UAV team consists of a Remote Pilot, a Visual Observer and/or Supporting Staff, the responsibilities are listed below:

Personnel	Responsibilities
Remote Pilot	Responsible for supervising and issuing command for UAV operation on-site. The duties include the following: • Conduct UAV flight in accordance with the flight plan, procedures set out in this document and any other applicable documents; • Ensure the overall safety of the UAV operations on-site; • Confirm that all members of the UAV Team are physically fit to carry out their duties; • Brief and debrief all members of the UAV Team and ensure they are aware of their responsibilities and tasks for the particular UAV operations; • Conduct risk assessment to identify any hazard for the operations and determine risk mitigating measures to be implemented; • Work out the flight details including flight time, flight duration, take-off and landing area, flight path, etc. and execute the flight accordingly; • Perform pre-flight check to ensure the UAV is in good condition and functions properly prior to take-off or launching; • Abort the UAV operations if the safety of persons or property on ground or in the air is in jeopardy, or if there is a failure to comply with the provisions of this manual; • Ensure that all logs and records in relation to the operations are properly completed and signed; and • Implement safety assurance measures.
Visual Observer	Responsible for assisting the remote pilot for the safe operations of UAV and maintaining Visual Line Of Sight with the UAV. The duties include the following: • Assist in the completion of all checks such as pre-flight and post-flight checks, and logs and records such as flight log and battery log; • Maintain direct, unaided (other than corrective lenses and/or sunglasses) visual contact with the UAV to know the UAV location, determine the UAV's attitude, altitude and direction of flight, observe the airspace for other air traffic or hazards and determine if the UAV become a hazard to any other aircraft, person or property; • Communicate continuously and effectively with the remote pilot and provide sufficient collision avoidance information to the remote pilot; • Inform the remote pilot when the UAV is approaching its maximum operating range limits; and

Personnel	Responsibilities
Supporting Staff	Dependent on the scale and complexity of the operation, supporting staff may be deployed. The duties include the following: • Keep the remote pilot updated constantly on an independent monitor on flight parameters of the UAV including battery level and satellites tracked; • Assist in ensuring the operation is executed according to plan such as flight paths followed and images captured; • Maintain constant visual lookout for any uninvolved person, vehicle, vessel or structure within or getting close to the minimum lateral separation required; and • Alert the remote pilot in case of any emergencies such as battery level and satellites tracked reaching the minimum level for safe operations.

5.3.2 Under the new regulatory regime following the commencement of the Small Unmanned Aircraft Order, classification of UAV in respect of each flight and its operations are as follows:

(i) UAV Category

Category	Description
Category A1	UAV weighing not more than 250 grams
Category A2	UAV weighing more than 250 grams but not more than 7 kilograms
Category B	UAV weighing more than 7 kilograms but not more than 25 kilograms

(ii) Operation

Category	Description
Standard Category A1 Operations	Operations of Category A1 UAV within applicable operating requirements
Standard Category A2 Operations	Operations of Category A2 UAV within applicable operating requirements
Advanced Operations	(a) Operations exceeding applicable operating requirements (except wholly within an enclosed area); (b) Operations of Category B UAV; (c) Operations of UAV carrying dangerous goods; and (d) Operations for which any part of the flight is within a restricted flying zone (except wholly within an enclosed area).

5.3.3 Remote pilots should register as a registered remote pilot under the Civil Aviation Department (CADept) for operating a UAV weighing over 250g outside of an enclosed area[6]. The remote pilot must be assigned the "standard rating" and "advanced rating" if using a Category A2 UAV and Category B UAV for the survey, respectively.

5.3.4 The UAV shall be registered under the CADept if it falls under Category A2 and Category B. The remote pilot shall follow the operating requirements of the standard or advanced operations as stipulated in the latest version of *Safety Requirements Document for Small Unmanned Aircraft Operations* issued by the CADept.

5.3.5 The survey team is required to apply for advance operation permission and submit the completed advance operation permission application form and the Operation Manual directly to the CADept before conducting advanced operations. All advanced operations shall be conducted in accordance with the flight plan, flight procedures, emergency procedures, risk assessment and safety mitigation measures documented in the Operation Manual accepted by the CADept. The Operation Manual should be comprehensive enough to incorporate all relevant procedures of each type of specified operation, and should be reviewed and updated from time to time.

5.4 Equipment Specifications

5.4.1 Appropriate type of UAV with necessary accessories and software meeting the requirements and specifications of the tasks should be used. The total weight of the UAV with accessories should be less than 7 kilograms at the time of take-off unless with endorsement by CADept. All the checking, maintenance works and repairs of the UAV and related accessories should be properly recorded.

5.4.2 UAV shall be equipped with the necessary safety system capable of performing the functions specified in section 13 of the Small Unmanned Aircraft Order (Cap. 448G), i.e. flight log and geo-awareness functions.

5.4.3 Geo-fence and altitude limiting functions shall be equipped to cage the UAV manoeuvres within a pre-defined flight area and level. RTK positioning system is recommended.

5.4.4 Appropriate ground station or remote controller software shall also be in place to assist the remote pilot in identifying the position of UAV in real time.

5.4.5 UAV equipped with obstacle avoidance function is recommended to provide an enhanced level of safety.

5.4.6 A maintenance schedule or tech log system shall be devised to form the programme for maintaining and servicing the UAV.

5.4.7 All personnel and crew members involved in the operations of Category B UAV including the remote pilot are recommended to be provided with appropriate high visibility personal protective equipment (e.g. reflective apparel, safety vests, etc.).

[6] A flight of UAV is within an enclosed area if the area is surrounded on all sides by fixed or movable walls, ceiling, structures or other barriers (excluding virtual fencing, e.g. geo-fence) that effectively prevent the aircraft from leaving the area during the flight.

5.5 Flight Requirements

5.5.1 The latest regulations published by CADept and the Government should be followed and observed, including but not limited to the following documents:

(i) Small Unmanned Aircraft Order (Cap. 448G);
(ii) Safety Requirements Document for Small Unmanned Aircraft Operations issued by the CADept; and
(iii) Drone Map for depicting the Restricted Flying Zones and their effective time

5.5.2 The UAV shall not be operated within a restricted flying zone or carry any dangerous goods during flight, unless a relevant permission has been separately obtained. For details of the restricted flying zone, please refer to Electronic Portal for Small Unmanned Aircraft.

5.6 Survey Procedures

5.6.1 The remote pilot determines the flight plan for achieving the purpose. A project area should to defined to ensure the maximum coverage of exposed UU can be achieved when determining the flight plan.

5.6.2 The remote pilot determines the most favourable take-off / landing site and the flying zone for avoiding endangering persons or properties on the ground and the appropriate time-slot for the UAV operations.

5.6.3 At least five GCP and three CP within the project area is required. The GCP should be located on stable, relatively level terrain and easily identified position. Additional GCP should be established and placed to achieve the required accuracy.

5.6.4 The remote pilot should conduct the UAV operations according to the flight plan.

5.6.5 To ensure the flight safety, the visual observer continuously monitors and provides parameters such as flying altitude, distance and velocity of UAV, battery level and number of satellites etc. to the Pilot. The supporting staff assists in spotting and alerting the team any sudden intrusion (approaching helicopters and birds, dogs, etc.) in the air and on the ground.

5.6.6 All unexpected incidents (e.g. crash, temporary incapacity of team members or any other persons interfering with the flight operations, abnormal behaviour, crash, etc.) should be properly recorded.

5.6.7 Before landing the aircraft, the remote pilot should alert the UAV team of the intention to land.

5.6.8 Upon touchdown, the remote pilot should stop the motors and switch off the UAV and then remote control after landing.

5.7 Survey Deliverables

5.7.1 Deliverables, including but not limited to field notes, computation sheets / data, photos, point cloud, survey drawings, GIS data and survey report, in respect of the survey, should be entered to the computation folder and certified by Professional Land Surveyor. The requirements are stipulated in Section 10.

6 PIPE CABLE LOCATING (PCL) / ELECTROMAGNETIC LOCATING (EML)

6.1 General

6.1.1 PCL/EML is comprising a transmitter and a receiver for the detection and identification of underground utilities with metallic property that can hold an electromagnetic charge.

6.1.2 PCL/EML shall be adopted to detect and identify underground utilities within the survey area by geophysical techniques. It is considered as Survey Type B in PAS 128 Underground utility detection, verification and location specification. The quality level achieved should be documented as QL-B. Deliverables of the survey shall include by not limited to Survey drawings and GIS data.

6.2 Accuracy

6.2.1 The survey work shall achieve the quality level of survey outputs stipulated in the PAS 128 Underground utility detection, verification and location specification. The quality level attained for each individual underground utilities feature should be included as one of the attributes in the GIS data.

PAS128 Quality Level	Criteria	Accuracy	Supporting Data
QL-B1	Horizontal accuracy	±150mm / 15% of the detected depth (whichever is greater)	Symmetrical field achieved resulted in peak and null measurements within B1 tolerance and/or present in GPR data where both depth estimates and horizontal location can be confidently established to the required accuracies. Only survey using active mode can reach this QL.
	Vertical accuracy	±15% of detected depth	
QL-B2	Horizontal accuracy	± 250mm or 25% of depth (whichever is greater)	Symmetrical field achieved resulted in peak and null measurements within B2 tolerance and/or present in GPR data where both depth estimates and horizontal location can be confidently established to the required accuracies. Only survey using active mode can reach this QL.
	Vertical accuracy	± 40% of detected depth	
QL-B3	Horizontal accuracy	± 500mm	Horizontal location detected by PCL/EML.

PAS128 Quality Level	Criteria	Accuracy	Supporting Data
	Vertical accuracy	Undefined (no reliable depth measurement)	EM field unable to estimate depth and horizontal accuracies within B2 tolerances with confidence.
QL-B4	Horizontal accuracy	Undefined	Suspected to exist but not detected.
	Vertical accuracy	Undefined	

6.3 Equipment Specifications

6.3.1 The signal transmitter should be capable of operating in at least six signal frequencies ranging from 500Hz to 200kHz. It should be available in each set of instrument for various active mode connection, and 50/60Hz and very low frequency, for passive power and radio mode detection. The output signal should be continuous with minimum 0.5 Watt output power, while a minimum 3 Watts power is required for locating most distribution systems, and more than 5 Watts is required for long distance traces or for utilities with high resistance joints. The transmitter should also be equipped with the accessories as below:

Accessories	Descriptions
Clamp	Made of split toroidal magnetic core.
Cable	Connect the transmitter to a remote ground point, cable should be supplied on a reel or drum.
Transmitting sonde	A self-contained waterproof transmitter emits signal that can be located by the receiver. It is commonly used for locating non-metallic pipes. Signal transmission frequency should correspond to a frequency on the PCL/EML receiver.
Plug connector (optional)	Connect the transmitter to live domestic socket onto the service cable and the distribution cable in the street.
Live cable connector (optional)	Connect the transmitter directly to a low voltage live conductor at a junction box or a substation. This method should only be used by competent person registered under Electrical and Mechanical Services Department of HKSAR Government.

6.3.2 For signal receiver, the locator set should be a combination of twin horizontal aerials (peak mode measurement), with one aerial mounted above the other, and a vertical aerial (null mode measurement). The basic specification of the receiver should include:

(i) An aerial and circuitry capable of readily receiving the transmitter frequency in active connection mode, 50/60Hz energy from power cables in passive power mode, very low frequency radio energy in passive radio mode, and Cable TV in passive mode;

(ii) Simultaneous visual and audio response to the signal. It can be either a loudspeaker or headphones;

(iii) Manual gain control for adjustment of receiver sensitivity or auto/manual gain

control to avoid the need for sensitivity level adjustment and keep the meter on scale;

(iv) An electronic depth measurement feature for measuring depth to the target; and

(v) Current measurement indication to allow confirmation of utility identity in congested areas.

6.3.3 All equipment to be used in the survey shall be calibrated by a calibration body or manufacturer in a specific interval as specified in the *Specifications for Nondestructive Testing, Surveying, Imaging and Diagnosis for Underground Utilities [NDTSID-UU-1,1] Pipe Cable Locating/ Electromagnetic Locating* published by the Hong Kong Polytechnic University. The certificate of calibration shall be available for inspection upon request by the Government Representative.

6.4 Survey Procedures

6.4.1 The survey operators should use personal protective equipment and have sufficient knowledge in both usage and maintenance of the equipment to minimise any potential risk of injuring. Personal protective equipment should include Steel toe cap, rubber safety boots, safety hamlet, safety vest (reflective at night), safety goggles / anti-glare glasses, gloves, earmuffs / ear plugs, handy gas detector.

6.4.2 Detail descriptions of passive mode survey, active mode survey, search, trace and depth measurement, and pinpointing and recording should refer to the latest version of the *Specifications for Nondestructive Testing, Surveying, Imaging and Diagnosis for Underground Utilities [NDTSID-UU-1,1] Pipe Cable Locating/ Electromagnetic Locating* published by The Hong Kong Polytechnic University.

6.5 Survey Deliverables

6.5.1 Deliverables, including but not limited to field notes, computation sheets / data, photos, survey drawings, GIS data and survey report, in respect of the survey, should be entered to the computation folder and certified by Professional Land Surveyor. The requirements are stipulated in Section 10.

7 GROUND PENETRATING RADAR (GPR) SURVEY

7.1 General

7.1.1 GPR works by sending high-frequency electromagnetic waves into the ground from a transmitting antenna and measuring the strength and time of any reflected signal. It is complementary to the method of PCL/EML and is able to detect utilities that PCL/EML cannot, such as plastic gas and water pipes, while also finding metallic pipes and cables. Deliverables shall include but not limited to Survey drawings and GIS data.

7.2 Accuracy

7.2.1 The recommended horizontal location (centreline of the utility) accuracy levels and accuracies of GPR Survey is as below:

Quality Level	Horizontal location accuracy
Reliable	± 150mm or ± 15% of detected depth whichever is greater. The accuracy level is only valid if alignment of utility is continuously observed in C-scan.
Survey unreliable	Undefined
Survey not successful	

7.2.2 A unique colour should be used to label survey unreliable / survey not successful utilities in drawings. The alignment and cover depth may be predicted from the survey drawing.

7.3 Equipment Specifications

7.3.1 The most common used GPR components are listed below:

Accessories	Descriptions
Transmitter and receiver dipole antenna	Transmitter: produces output pulses radiating into the ground Receiver: receives the EM waves reflected from interface between media with significant contrast of dielectric properties and conductivity, and amplifies them for analysis
Radar control unit	Converts analogue radio signal to digital format
Data storage	/
Display devices	/

7.3.2 The antenna receives the electrical pulse produced by the control unit, amplifies and transmits it into the ground or other medium at a particular frequency. The higher the frequency of the antenna, the shallower into the ground it will penetrate. The recommended antenna frequency, approximate depth penetration, and appropriate application are listed below:

Depth range (approximate) (m)	Primary antenna choice (MHz)	Secondary antenna choice (MHz)	Appropriate application
0 – 0.5	1500	900	Structural Concrete, Roadways, Bridge decks

Depth range (approximate) (m)	Primary antenna choice (MHz)	Secondary antenna choice (MHz)	Appropriate application
0 – 1	900	400	Concrete, Shallow soils
0 – 3	400	200	Shallow Geology, Utilities
0 – 9	200	100	Geology, Environmental, Utility
0 – 30	100	Sub-Echo 40	Geologic Profiling
Greater than 30	MLF (80, 40, 32, 20, 16)	/	Geologic Profiling

7.3.3 All equipment to be used in the survey shall be calibrated by a calibration body or manufacturer in a specific interval as specified in the *Specifications for Nondestructive Testing, Surveying, Imaging and Diagnosis for Underground Utilities [NDTSID-UU-1,2] Ground Penetrating Radar* published by the Hong Kong Polytechnic University. The certificate of calibration shall be available for inspection upon request by the Government Representative.

7.4 Survey Procedures

7.4.1 Field survey

(i) Site environment, difference with the information available in desktop study should be recorded.

(ii) The construction details, ground surface damage and deformation, soil conditions observable in nearby trail pits, water seepage, anticipated properties of the target and host material, the topography, and access to the site. Any sources of electromagnetic noise, radio, operational constraints should be recorded and avoided as much as possible.

(iii) Check of the battery condition, complete set of equipment and relevant information.

(iv) Calibration of wheel

A fixed distance to be decided on-site, the wheel is towed over that distance and the number of hits are counted. The ratio between the actual distance and the count becomes the calibration factor for a particular survey area. This process must be repeated three (3) times and an average of the ratio is then calculated.

(v) Calibration of dielectric constant

(vi) Data acquisition following grid design

(vii) Record the field data clearly, save the field document and data, clean up the field and pack the equipment in order.

7.4.2 Post-processing

For detail procedures, please refer to the latest version of the *Specifications for Nondestructive Testing, Surveying, Imaging and Diagnosis for Underground Utilities*

[NDTSID-UU-1,2] Ground Penetrating Radar published by the Hong Kong Polytechnic University.

7.5 Survey Deliverables

7.5.1 Deliverables, including but not limited to field notes, computation sheets / data, raw and processed data, survey drawings, GIS data and survey report, in respect of the survey should be entered to the computation folder and certified by Professional Land Surveyor. The requirements are stipulated in Section 10.

8 CLOSE RANGE PHOTOGRAMMETRIC SURVEY

8.1 General

8.1.1 Digital camera is used as survey equipment to capture data such as photographs and videos of ground features for engineering and development works. From collected data, a photogrammetric software can create geo-referenced orthomosaics, elevation models or 3D models of the project area. Deliverables shall include but not limited to Geo-referenced point cloud data, survey drawings and GIS data.

8.1.2 Close range photogrammetry shall be adopted to confirm and record the location and other attribute data of the exposed target utilities within the survey area. It is also considered as Survey Type A in PAS 128 Underground utility detection, verification and location specification. The quality level achieved should be documented as QL-A.

8.2 Accuracy

8.2.1 Close range photogrammetry should be performed with the following accuracy requirements.

PAS128 Quality Level	Criteria	Accuracy	Supporting Data
QL-A	Horizontal accuracy	± 50mm	Horizontal and vertical location of the top, bottom or centreline of the utility.
	Vertical accuracy	± 50mm	

8.2.2 The point cloud data should be checked with at least 3 check points and 3 tie measurements with the tolerance as below:

Check Point	
Northing	± 50mm
Easting	± 50mm
Height	± 50mm
Tie Measurement	
Tolerance	± 50mm

8.2.3 Establishment of Control Points

(a) Establish control points on features with characteristics below:

(i) On stable structure

(ii) Well defined features on relatively flat horizontal surface

(iii) High contrast between foreground and background

(iv) Coded target provided by photogrammetric software

(b) Minimum 4 control points are required. Control points shall be distributed evenly along the sides of the trench, trial pit or manhole. Additional control points may be digitised for enhancing the accuracy.

8.2.4 Minimum 3 check points for independent check should be established. The quantity depends on the scale of the site. The accuracy of check points should meet the acceptance criteria stated in Paragraph 8.2.2.

8.2.5 Minimum 3 tie measurements are required. Minimum two tie measurement shall across the distance of the half of the trench to assess any distortion of the model.

8.2.6 The 3D positions of all check points should be surveyed by survey method such as radiations from a known control stations by total station or RTK measurement by GNSS and geo-referenced to HK 1980 Grid and HKPD.

8.3 Equipment Specifications

8.3.1 Digital camera used for close-range photogrammetry has to be calibrated before use for the first time or after repair and thereafter at least once a year.

8.3.2 Computation of Calibration Parameters

(i) Use photogrammetric software which support automatic lens calibration.

(ii) Print / Display the calibration pattern (generate by the software) on paper/screen.

(iii) Capture a series of images of the calibration pattern with the digital camera from different angles.

(iv) Capture the calibration pattern filling up the whole images.

(v) Make sure all the settings keep constant throughout the session.

(vi) Import the images into the photogrammetric software for camera calibration.

8.3.3 Validation of Calibration Parameters

(i) Identify a testing site with distance from camera to target plane is suitable for enabling the photogrammetric software to automatically detect the coded targets.

(ii) Prepare and place the coded targets on the target plane.

(iii) At least 6 coded targets should be placed evenly over the calibration site.

(iv) Take photos with more than 80% overlap and capture the coded targets perpendicularly whenever practicable.

(v) Survey the position and height of coded target by total station. For simplicity, the field work can be performed based on an arbitrary coordinate system.

(vi) Process the data in photogrammetric software using the calibration parameters computed in Paragraph 8.3.2.

(vii) Compare the result from 3D model with the surveyed data of coded target.

(viii) If the result is within acceptable tolerance of 50 mm in Northing and Easting while 50 mm in height, the calibration parameters should be applied in close range photogrammetric survey projects.

(ix) If the result significantly exceeds the acceptance criteria, the digital camera should not be used in close range photogrammetric survey.

8.3.4 If the photogrammetric software supports automatic camera calibration and allows for on-the-job calibration, there is no need for manual calibration of the digital camera mentioned above.

8.4 Survey Procedures

8.4.1 Field Survey

(i) The operator should prepare an equipment checklist to check for all equipment used.

(ii) Survey control stations should be established at locations in accordance with Section 3. GNSS or traversing may be adopted as the survey method for establishing the control network.

(iii) Establish minimum 4 control points. For large survey area, establish additional control points at an interval of 100 m.

(iv) At least 3 check points should be established for checking. The accuracy should be meet the accuracy standard stated in Paragraph 8.2.2.

(v) Take tie measurements on some features. Minimum 3 pairs of tie measurements should be established.

(vi) Target objects, control points and check points should be captured from multiple viewpoints (at least 3 images).

(vii) Ensure the surveyed object is located within the range limit of the camera and start the survey. The surveyor should circle around the target utility to capture photos and take small steps to ensure a minimum 80% overlap and a maximum angle difference of 15° is maintained between consecutive photos.

8.4.2 Recommendation and Shooting Tips

(i) Camera settings:

- At least 5 megapixel
- Output format: RAW or TIFF or JPEG
- Low ISO (ISO400 or below)
- High Shutter speed (1/125 or above)
- Avoid the use of ultra-wide lens or fisheye lens
- Use fixed lens as possible
- Use same aperture, ISO and shitter speed settings

(ii) Make sure the quality and completeness of the captured data by viewing the photos on-site. Ensure the target utility, control points and check points are captured. Constant and homogeneous lighting shall be maintained. Avoid blurry photos and flash light.

8.4.3 Post Processing

(i) Photos shall be aligned together automatically by software or manually by tie-point/tie-point constraint method.

(ii) Digitise the control points and import the respective survey data in the software for geo-referencing.

(iii) Review the quality report generated by the software and assess the accuracy of the check points and tie-measurement.

(iv) Output point cloud and edit point clouds in point cloud editing software.

(v) Filter out unwanted point clouds.

8.5 Survey Deliverables

8.5.1 Deliverables, including but not limited to field notes, computation sheets / data, photos, point cloud, survey drawings, GIS data and survey report, in respect of the survey, should be entered to the computation folder and certified by Professional Land Surveyor. The requirements are stipulated in Section 10.

9 SURVEY EQUIPMENT

9.1 Survey equipment should be handled, stored and used in accordance with manufacturer's recommendations. All the equipment deployed to the survey should be calibrated against the procedures traceable to the recognised national or international standards and at intervals not exceeding 6 months, or immediately after the equipment is repaired or serviced. All calibration records should be properly recorded for each of equipment.

9.2 For the distance measuring equipment, such as Steel Tape, Electronic Distance Meter and GNSS, all equipment should be calibrated against the baseline or network established and adopted for calibration by the SMO of LandsD.

9.3 All equipment used / selected should be suitable for attaining the accuracy and precision required and the purpose of the survey / project.

9.4 Records of calibration of all equipment should be properly recorded.

10 DELIVERABLES FOR UU SURVEYS

10.1 Deliverable Requirement

10.1.1 Survey deliverables shall be submitted to WDs for facilitating UUIS updating. The following table summarises the essential deliverables to be prepared for each methodology adopted in the UU survey.

	Survey Methodology[7]				
	LS	**UAV**	**PCL/ EML**	**GPR**	**CRP**
1. Site photos with photo index	✓	✓	✓	✓	✓
2. Raw data	✓	✓	✓	✓	✓
3. Processed point cloud	✓	✓	✗	✗	✓
4. Survey drawings	✓	✓	✓	✓	✓
5. GIS data	✓	✓	✓	✓	✓
6. Survey report	✓	✓	✓	✓	✓

10.1.2 All deliverables of the survey job shall be compiled into a computation folder, and certified by a Professional Land Surveyor before submission.

10.2 Site Photos with Photo Index

10.2.1 Site photos, with date and time clearly shown, should be taken during the survey. A photo index plan should also be prepared for indicating the location and direction of the photo taken. The site photos should be prepared in commonly readable format (e.g., JPEG) and the image size for each photo should not be less than 2 mega pixels.

10.3 Raw Data

10.3.1 Raw data refers to the data collected and captured by survey instruments, which includes but not limited to the field notes for control survey, survey raw data, point cloud data and digital photos.

10.3.2 Field Notes

(i) The original records of field observations and measurements recorded in the field in the course of the survey shall be submitted as the raw data of control survey. All original field notes should be properly recorded, kept and attached to the survey report as an appendix.

(ii) The first page of the field notes of every survey should by certified by Professional Land Surveyor, which the survey is carried out either by himself/ herself or under his/her immediate direction and supervision.

[7] LS: Laser Scanning Survey; UAV: Photogrammetric Survey by Unmanned Aerial Vehicle; PCL/EML: Pipe Cable Locating or Electromagnetic Locating Survey; GPR: Ground Penetrating Radar Survey; CRP: Close Range Photogrammetric Survey

10.3.3 Survey Raw Data

(i) The survey raw data (in csv format) downloaded from electronic data recorder should be properly stored and kept.

10.3.4 Point Cloud Data

(i) The point cloud data captured in the laser scanning survey should be processed to deliver geo-referenced and colourised point cloud data. It is not necessary to submit the raw point cloud data. Other operational details, including field operation and data processing parameter, survey data of control stations and any other items, should be compiled in the survey report.

10.3.5 Digital Photo

(i) The aerial photos captured in photogrammetric survey for generating 3D point cloud data should be submitted associated with the computation folder.

10.4 Processed Point Cloud

10.4.1 It is mandatory to submit the colourised and geo-referenced point cloud except for PCL/EML and GPR survey.

10.4.2 The 3D point cloud deliverable shall follow the requirements stated below.

Format	ASCII, LAS or E57
Coordinate System	HK 1980 Grid for horizontal; HKPD for vertical
Attribute	Include but not limited to X, Y and Z coordinates, intensity, Red, Green and Blue values

10.4.3 The specification for the LAS data format should follow the latest version of *LAS Specification* published by the American Society for Photogrammetry & Remote Sensing.

10.4.4 If the 3D point cloud is mosaicked using multiple data scans, the accuracy of the point cloud registration should be reported. The provision of optional files, including photorealistic 3D models, and unfolded views of panoramic (RGB/Intensity/Thermal Infrared) images is highly recommended.

10.4.5 When the photogrammetric survey is adopted, it is recommended to deliver either orthophoto in GeoTIFF format, or 3D photorealistic models in FBX, 3DS, OBJ, or 3MX formats for better visualisation. The quality and accuracy should also be checked before submission.

10.5 Survey Drawing

10.5.1 The location and details of the surveyed UU data shall be clearly depicted on the survey drawing. It should be prepared in compliance with the latest version of the *Computer-Aided-Drafting Standard for Works Projects* available on the website of Development Bureau and the *Drafting Specifications for Engineering Survey* available on the website of Civil Engineering and Development Department.

10.5.2 As-built plans in both hardcopy and softcopy should be prepared and submitted. The softcopy of as-built files should be delivered in MicroStation (DGN) file format or AutoCAD (DWG) file format as specified.

10.5.3 The as-built data shall be geo-referenced and prepared with correct geometry and contain relevant attributes data, including but not limited to the unique identifier, category, owner, size and depth. The following points concerning the survey drawings shall be followed:

(i) The alignment, depicted in different colours, and respective depth of any utilities within the site boundary shall be presented at an interval of 5m in discrete areas or with intervals not exceeding 10m for survey along the road, and at each surface feature, change of direction and bifurcation in a utility drawing at 1:100 or 1:200 scale, or in a scale agreed with the client;

(ii) In the drawing, utilities shall be connected to identified ground features like roads and buildings contained in location plan, and indicate change of direction, if any. All reported coordinates and levels are referenced to the HK1980 Grid Datum and the HKPD respectively. (The coordinates for N,E are presented as 8*****.***, 8*****.***, relative to the HK1980 Grid Datum. Normally, "All levels are referred to HKPD" and must be present in the survey plan);

(iii) The depth shall be annotated at each recording point and at positions with significant changes of depth. The depth of metallic utilities shall be shown using the notation with a cross mark on each respective utility. The electrical current levels of the locations at which depth is measured and at the active connection point shall be recorded in the worksheet; and

(iv) The depth of metallic utilities detected by PCL/EML shall be referenced to the centre of the pipes/cables and the inverts of gravity utilities such as sewers and drains if sonde is used or the measurement is through manhole survey.

10.6 GIS Data

10.6.1 The processed point cloud data should further be converted to GIS format, as specified in the latest version of the Data Specification of UUIS prepared by the LandsD.

10.6.2 The information of the target utility shall be extracted by digitising the centerline of the target utility and export to ESRI file geodatabase format (FGDB).

10.6.3 The geodatabase shall contain information of the system defined fields and data owner defined fields that stated in the *Data Specification of UUIS prepared by the LandsD*.

10.7 Survey Report

10.7.1 A Survey Report shall be prepared for presenting the survey procedures, methodology and derived results in detail. It should include but not limited to the following content:

(i) Description of the site with location plan, site photo and photo index;

(i) Site-specific method statement for the survey, including equipment details, calibration certificates, survey instrument configurations, data acquisition methods, data processing, and quality checks;

(ii) Description explaining the survey process, results, and attained accuracy;

(iii) Summary of survey control points and check points, including photos and distribution diagram. Appendix should include station name, reference number, coordinates with respect to HK 1980 Grid, height above HKPD, type of station marker, and general location;

(iv) Reports of computerised processes generated by the data processing software, with focus on achieved accuracy (if applicable);

(v) Summary of underground utilities feature captured during the survey;

(vi) Reports of findings and recommendations;

(vii) Site constraints (if applicable);

(viii) UAV flight parameters and operational records, such as flight records, risk assessment forms, and flight plans *(applicable for photogrammetric survey by UAV only)*;

(ix) Report of findings and interpretations in the form of C-scans images and representative B-scans *(applicable for GPR survey only)*; and

(x) Calculated uncertainties of depth measurement of utilities according to Guideline of Uncertainty Measurement *(applicable for GPR survey only)*;

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