How can Technologies of Nondestructive Utility Survey be Standardized in Specifications?

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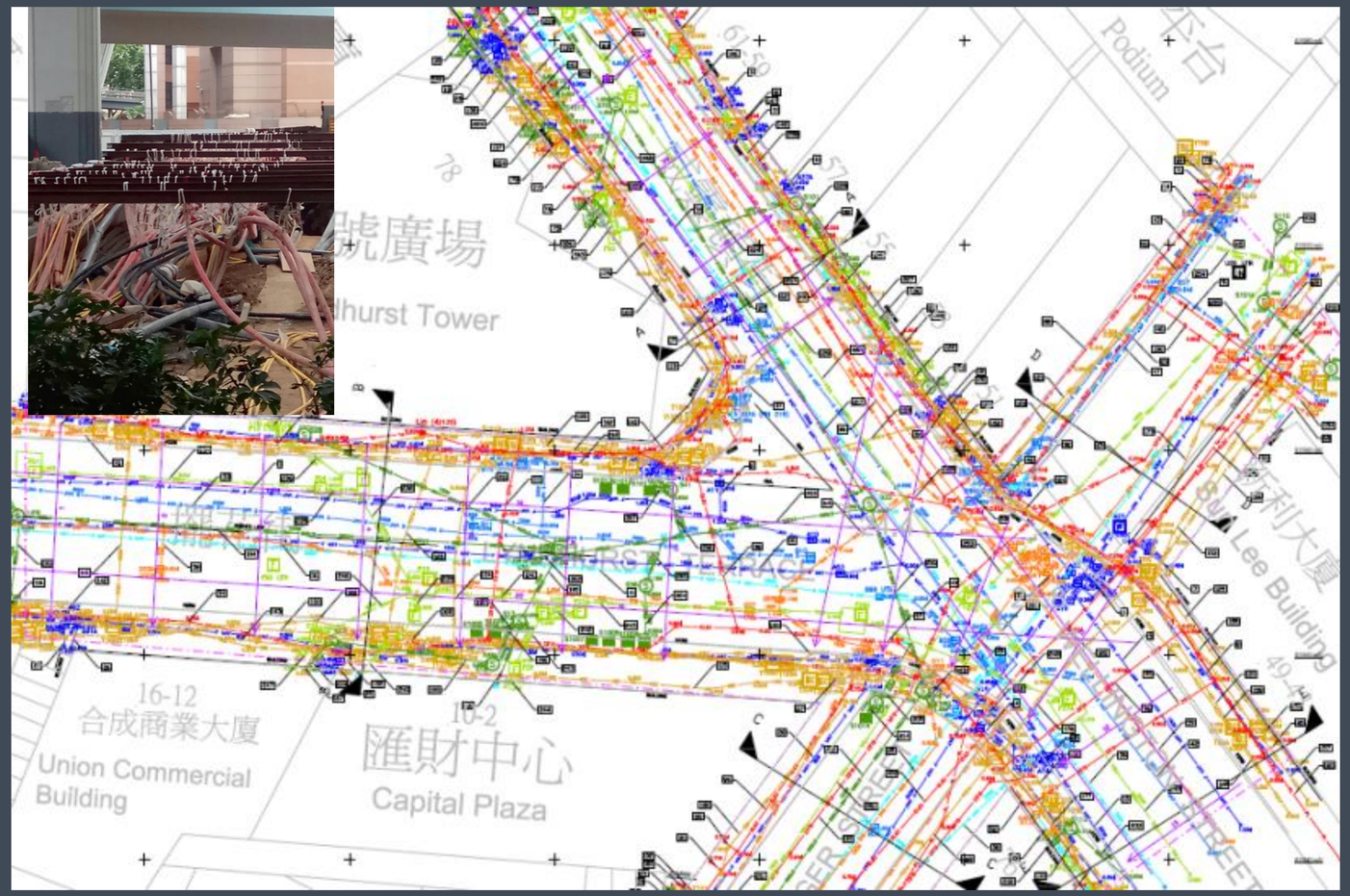
Densely populated underground (1km long road 47km UU according to MTR)

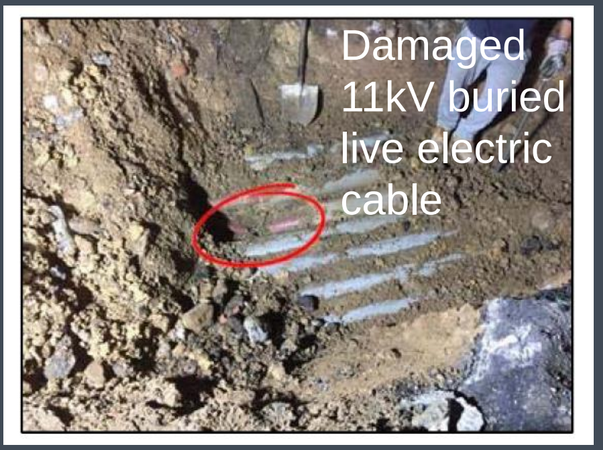


屯盛街近青山公路 – 青山灣段因水管爆裂，屯盛街來回方向介乎青山公路 – 青山灣段與屯發路之間的全線現已封閉。 駕駛人士請考慮改用其他道路。 9 Sep 2020

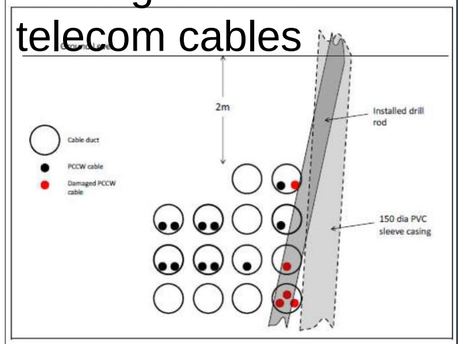
Source: Wong K. guest lecture for LSGI, PolyU, 12 March 2014

Accidents about UU

Bursting of WSD dia. 450 mm Fresh Water main



Damaged PVC telecom cables



Reasons: Implementation of Permit to work/dig, slant drill bit, unknown alignment of a pressurized main during road re-surfacing, CP's competency…. (Source: MTR)

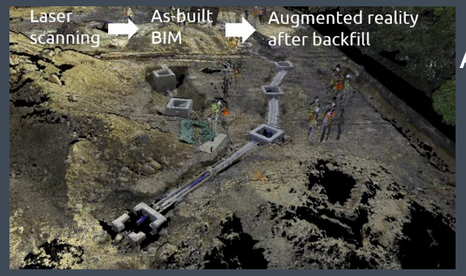
6 common NDTSID-UU technologies to be standardized in specs

1,1 Pipe Cable Locator

EM method to trace and locate buried UU alignment using passive or active method

1,2 Ground Penetrating Radar

EM method to located buried objects and detect abnormalities like voids and water seepage



1,3 Laser Scanning

As-built survey of open trench

2,1 Visual Inspection

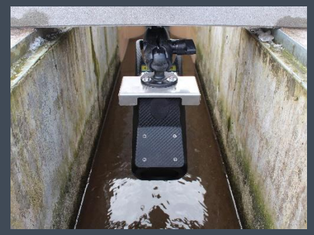
pipe and manhole condition

2,2 Acoustic Emission

Source water seepage and locate leak points

2,3 Flow Survey

Measure flow velocity and depth of fluid in pipe



Solutions based on technologies analogous to medical imaging and diagnosis

Accuracy guidelines of UU mapping survey (BSI PAS 128:2014)

Table 1 – Quality level of survey outputs (normative)

Survey type (Establish with client prior to survey)		Quality level (Practitioner to determine post survey)	Post-processing	Location accuracy		Supporting data
				Horizontal [1]	Vertical [2]	
D	Desktop utility records search	QL-D	—	Undefined	Undefined	—
C	Site reconnaissance	QL-C	—	Undefined	Undefined	A segment of utility whose location is demonstrated by visual reference to street furniture, topographical features or evidence of previous street works (reinstatement scar).
B	Detection [3]	QL–B4	No	Undefined	Undefined	A utility segment which is suspected to exist but has not been detected and is therefore shown as an assumed route.
	PCL	QL-B3	No	±500 mm	Undefined (No reliable depth measurement possible)	Horizontal location only of the utility detected by one of the geophysical techniques used.
	GPR	QL-B3P	Yes			
	PCL	QL-B2	No	±250 mm or ±40% of detected depth whichever is greater	±40% of detected depth	Horizontal and vertical location of the utility detected by one of the geophysical techniques used. [4]
	GPR	QL–B2P	Yes			
	PCL	QL-B1	No	±150 mm or ±15% of detected depth whichever is greater	±15% of detected depth	Horizontal and vertical location of the utility detected by multiple [5] geophysical techniques used.
	GPR	QL–B1P	Yes			
A	Verification	QL-A	—	±50 mm	±25 mm	Horizontal and vertical location of the top and/or bottom of the utility. Additional attribution is recorded as specified in 9.2.5.

[1] Horizontal location is to the centreline of the utility.
[2] Vertical location is to the top of the utility.
[3] For detection, it is a requirement that a minimum of GPR and EML techniques are used (see 8.2.1.1.2).
[4] Electronic depth readings using EML equipment are not normally sufficient to achieve a QL-B2 or higher.
[5] Some utilities can only be detected by one of the existing detection techniques. As a consequence, such utilities cannot be classified as a QL-B1.

PAS 128-2014 Specification for Underground Utility Detection, Verification and Location

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UUS | SPEC
SPECIFICATIONS FOR NONDESTRUCTIVE TESTING, SURVEYING, IMAGING AND DIAGNOSIS FOR UNDERGROUND UTILITIES

Development of Specifications and Standards for Underground Utility (UU) Survey based on *Nondestructive Testing, Surveying, Imaging and Diagnostic (NDTSID) Approaches* funded by Innovation Technology Fund - General Support Scheme project

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森記建築有限公司
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CHKSTT
CHINA HONG KONG SOCIETY FOR TRENCHLESS TECHNOLOGY

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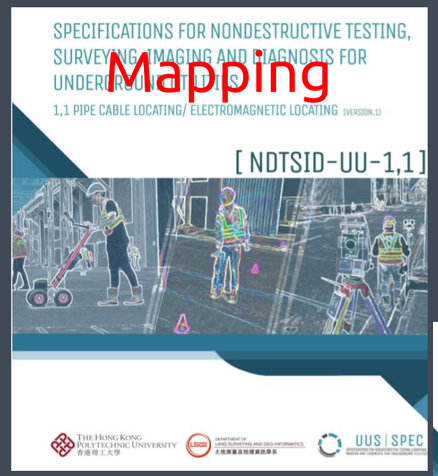
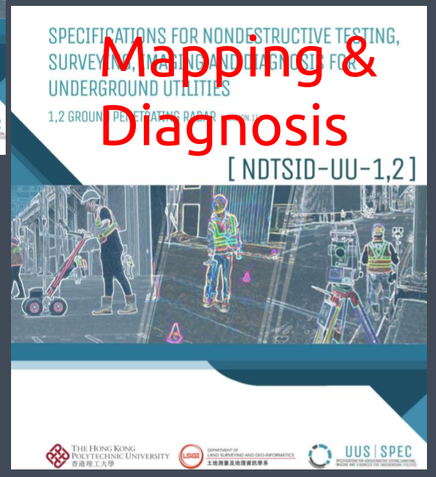
Hong Kong Institute of Utility Specialists

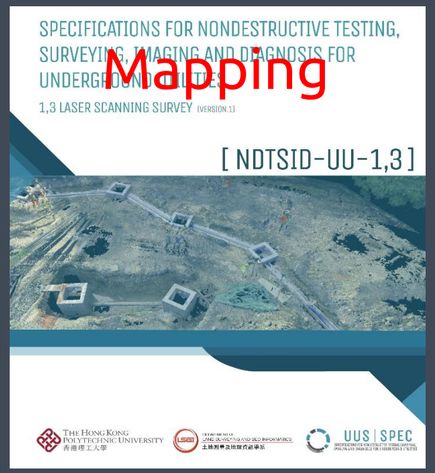
Technologies for all surveys including (1) mapping and (2) imaging and diagnosis: Specifications and Accreditations



Pipe cable locating/ electomagnetic locating



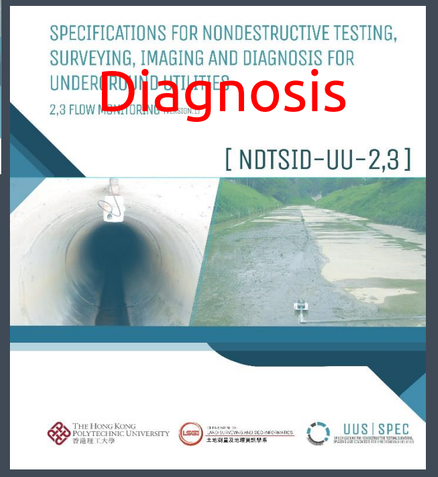
Ground penetrating radar



Laser Scanning

Visual inspection

Acoustic Emission Method for leak detection in pressurized water –carrying utilities



Flow Monitoring for gravity water-carrying utilities

A set of six underground utility survey specs (funded by ITF and to be implemented by HKAS through HOKLAS in 2021 Q1), freely download at https://www.polyu.edu.hk/lsgi/uusspec/en/publications/

Spec based on 4M 1E for accreditation (Not interpretation!)

Method 法

- Documentation (traceability)
- Working procedures/ Testing manual
- Analytical calibration methods
- Repeatability and accuracy control
- Uncertainties
- Validation of results

Man/Woman 人

- Staff Qualification and Certification
- Training Record
- Duty record
- …….

Material 物

- Procedure for taking, preserving and/or storing samples
- Procedure for receiving samples
- Labelling system

Machine機

- Labelling (Identification of the equipment)
- Annual calibration plan
- Calibration certificate
- Maintenance records
- …….

Environment 環

- Testing environment
- Workplace
- Material Storage

Spec 1,1 PCL/EML

https://www.polyu.edu.hk/lsgi/uusspec/en/publications/

Part C Man/ Woman

Part D Machine

Part E and F Methods, Materials, Environment

Part G and H Deliverables

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

Table of Contents

Spec 1,2 GPR

https://www.polyu.edu.hk/lsgi/uusspec/en/publications/

Part C
Man/
Woman

Part D
Machine

Part E and F
Materials
Methods,
Environment

Part G and H
Deliverables

Table of Contents

Man/Woman 人 (e.g. 1,1 PCL/EML)

C2 – Signatory

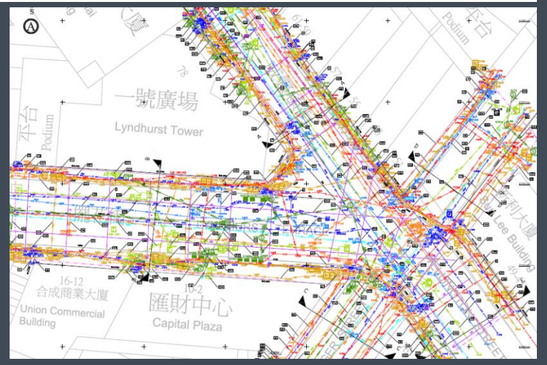
C2,1 A **Signatory** of a report shall either have:

(i) a Bachelor of Science (e.g. Geomatics/Land Surveying) or Engineering (e.g. Civil/Electrical/Materials/Mechanical/Gas/Industrial) degree with specialization in underground-utility (UU) survey or a Bachelor of Science (e.g. Geomatics/Land Surveying) degree with not less than 200 contact hours of BSc/BEng's UU training, provided by a recognized tertiary institution plus at least ***three*** years of technical and managerial experience of underground utilities, within which a period of two years is substantially[1] related to the subject matter in this specification, or

(ii) a valid certificate or diploma[2] of specialization in PCL/EML issued by a recognized organization operating under international standards or qualifications framework level 4 plus at least ***five*** years of technical and managerial experience of underground utilities, within which three years are substantially related to the subject matter in this specification, or

(iii) at least a higher certificate or diploma issued by a recognized technical institute or an equivalent qualification in a relevant discipline, with at least ***seven*** years of direct technical and managerial experience, within which five years are directly related to the subject matter in this specification, plus relevant training courses[2] covering the content in this specification.

[1] Direct technical and managerial involvement in 10 test/survey reports in different contracts/works orders.
[2] A typical certificate or diploma shall include all aspects covered in this specification.



C3 – Survey Officer

C3,1 A **Survey Officer** shall normally be supervised by a Signatory having the necessary qualifications, experience and technical knowledge. A Survey Officer shall be a competent person for locating electricity cables approved under The Electricity Supply Lines (Protection) Regulation, made under the Electricity Ordinance, Cap. 406H, and shall either have

(i) a higher diploma or above (e.g. Geomatics/Land Surveying) or an engineering higher diploma or above (e.g. Civil/Electrical/Materials/Mechanical/Gas/Industrial) with not less than 75 contact hours of UU training provided by a recognized tertiary institution, plus at least ***one*** year of on-the-job experience substantially[3] related to the subject matter in this specification, or

(ii) a valid certificate or diploma[4] of specialization in PCL/EML issued by a recognized organization operating under international standards or qualifications framework level 3 plus at least ***two*** years of substantial on-the-job experience[3] related to the subject matter in this specification, or

(iii) at least a higher certificate or diploma issued by a recognized technical institute or an equivalent qualification in a relevant discipline, plus at least ***three*** years of substantial on-the-job experience[3] related to the subject matter in this specification, plus relevant training course covering the content in this specification[4].

(iv) at least ***eight*** years of substantial on-the-job experience[3] related to the subject matter in this specification.

[3] On-the-job direct involvement in 10 test/survey reports in different contracts/works orders.
[4] A typical certificate or diploma shall include all hands-on aspects covered in this specification.

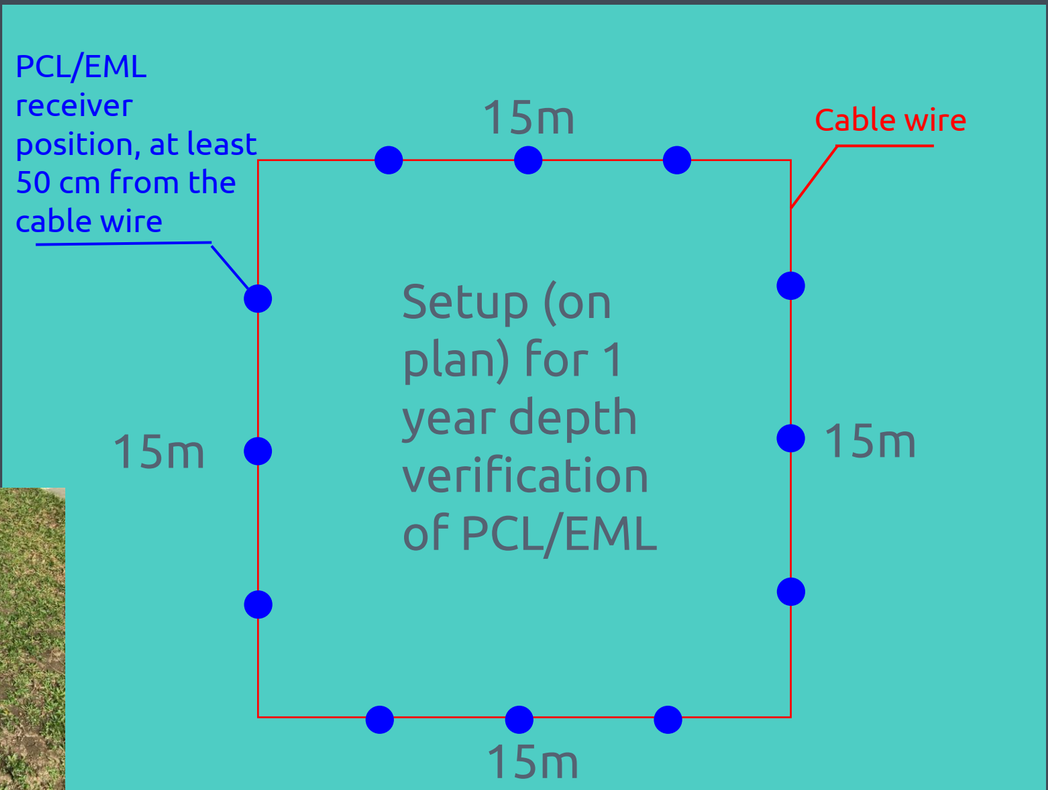
C3,2 A Survey Officer shall be evaluated based on technical competence and the lab/survey company is required to keep a separate list of qualified Survey Officers who are permitted to perform each survey/test and sign the worksheet, for the purpose of checking by the Accreditation Body. As approvals are granted in the context of the survey/tests being performed by a particular lab/survey company, they shall not be considered as personal qualifications.

Machine 機 (e.g. 1,1 PCL/EML)

Table 3 Specific Calibration/Verification Requirements

Type of equipment	Maximum period between successive calibration/verification	Calibration/verification procedure or guidance documents and equipment requirements
Pipe Cable Locator/Electromagnetic Locator	5 years (calibration)	Calibration shall be conducted by a competent calibration body as defined in HOKLAS Supplementary Criteria No. 2 or manufacturer.
	1 year (depth verification)	Accuracy requirement provided by the manufacturer shall be complied, and shall be better or equivalent to equipment specifications. Procedure in Section D3 shall be followed.
	Before each test (verification before use)	Self-test suggested by the manufacturer
Other equipment related to this PCL/EML survey (e.g. total station, digital level)	1 year (calibration)	Accuracy requirement provided by the manufacturer shall be complied.

The depth verification shall be performed in an open area, away from any steel or reinforced concrete structure that would cause distortion of the magnetic field. A typical 5-step procedure is suggested as follows: (1) lay a 60 m long wire and bend it into a square of 15 m x 15 m and connect the transmitter to both ends of the wire. (2) switch the transmitter to all frequencies ranging from 500 Hz to 200 kHz and trace at least 12 points on the wire loop. (3) position the receiver where a peak response over a distribution of low-high-low magnetic field is resulted. Repeat the trace with any step frequency between 500 Hz to 200kHz available in the equipment. (4) for every test, position the receiver on a wood / plastic platform right above the wire so that the bottom of the receiver is at least 50 cm above the centre of the wire. (5) measure the receiver's distance along the wire at 3m intervals along the loop starting from any corner, but do not take a measurement at the four corners. All values must fall within the acceptance criteria suggested by the manufacturer.



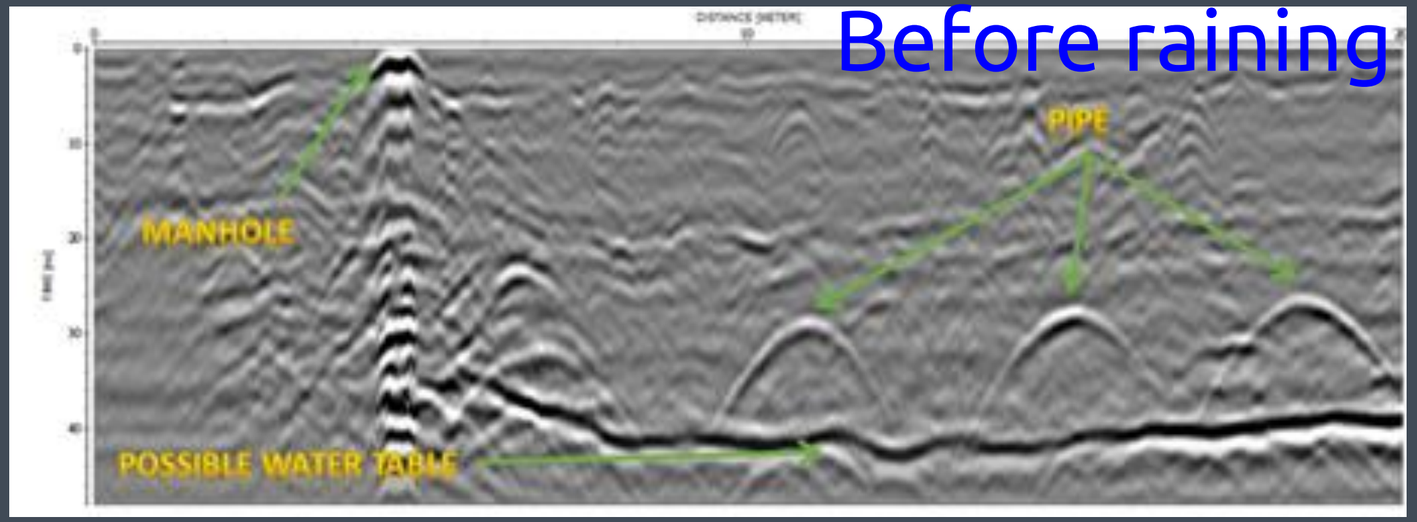
Acknowledgement: Mak Wai-Fung, Wilfred 3M (Hong Kong) Ltd.

Material 物 (e.g. 1,2 GPR)

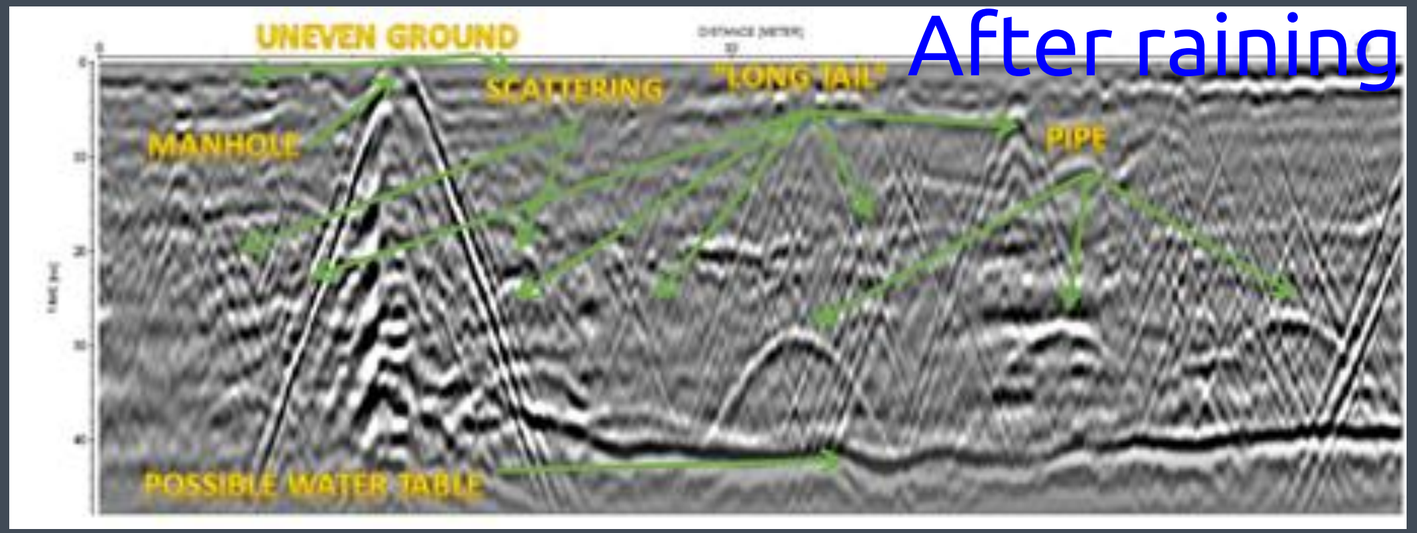
Table 1 Approximate Electromagnetic Properties of Various Materials (ASTM D6432-11, 2011)

Material	Relative Permittivity ε′	Wave velocities (m/ns)	Conductivity (mS/m)
Air	1	0.3	0
Fresh water	81	0.033	0.10 – 30
Sea water	70	0.033	400
Sand (dry)	4-6	0.15-0.12	0.0001 – 1
Sand (saturated)	25	0.055	0.1 – 1
Silt (saturated)	10	0.095	1 – 10
Clay (saturated)	8-12	0.106-0.087	100 – 1000
Dry sandy coastal land	10	0.095	2
Fresh water ice	4	0.15	0.1 – 10
Permafrost	4-8	0.15-0.106	0.01 – 10
Granite (dry)	5	0.134	0.00001
Concrete	5-10	0.134-0.095	
Asphalt	3-5	0.173-0.134	
Sea ice	4-12	0.15-0.087	
PVC, epoxy, polyester vinyl, rubber	3	0.173	

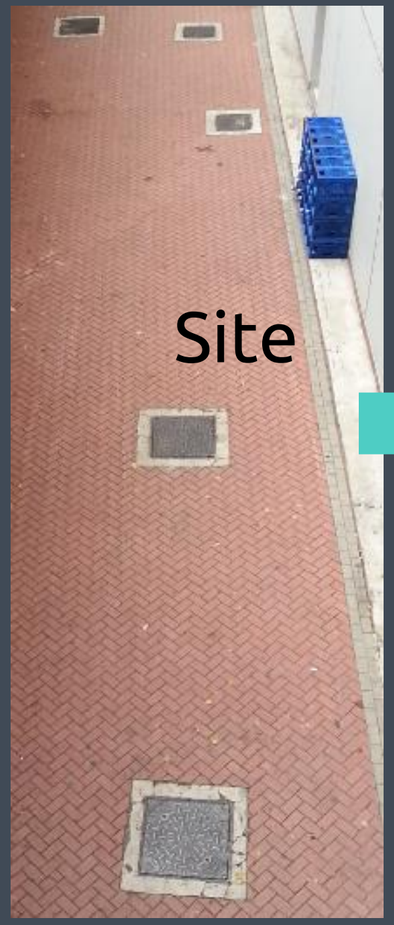
Before raining



After raining



Method 法 (e.g. 1,2 GPR)



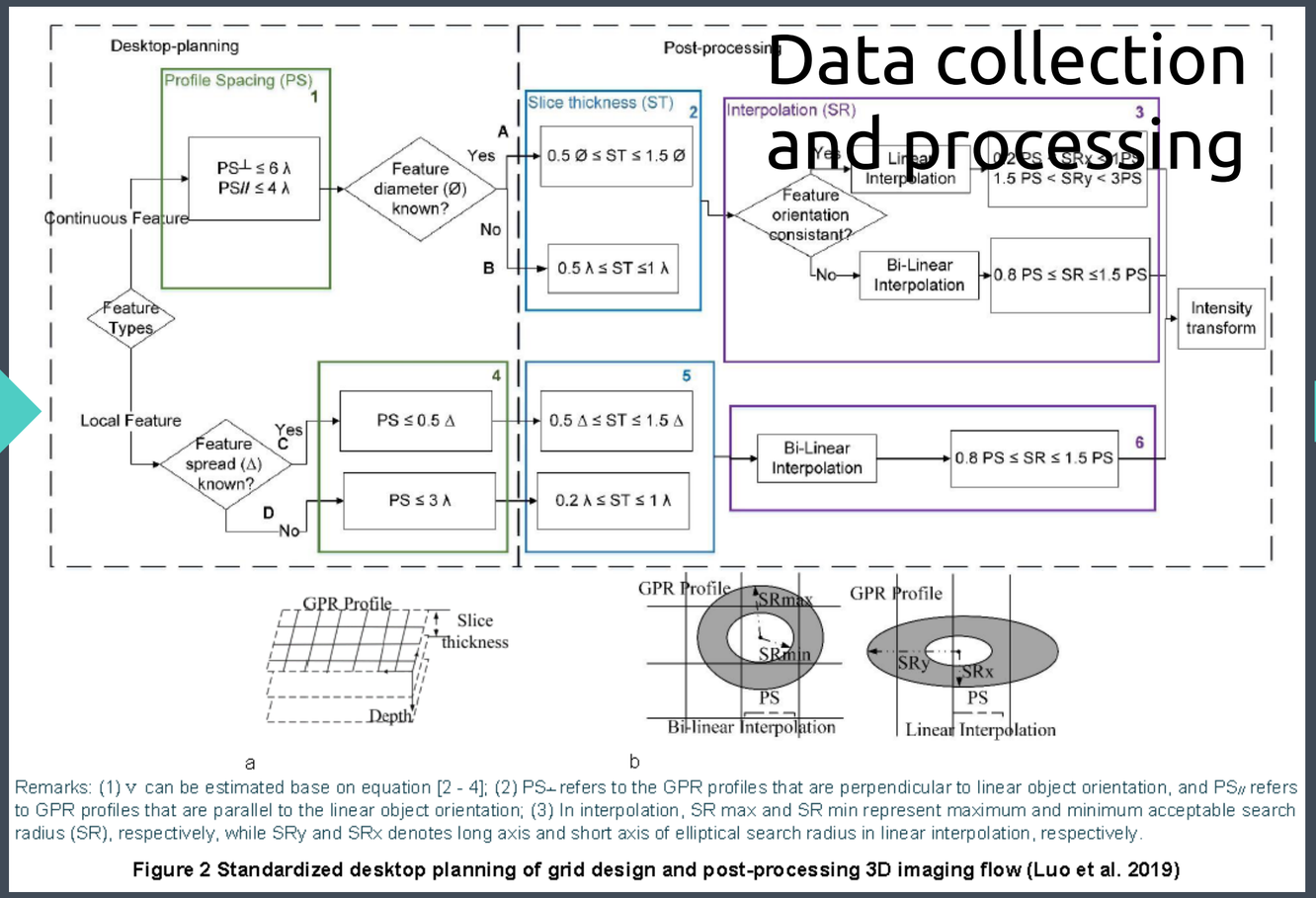
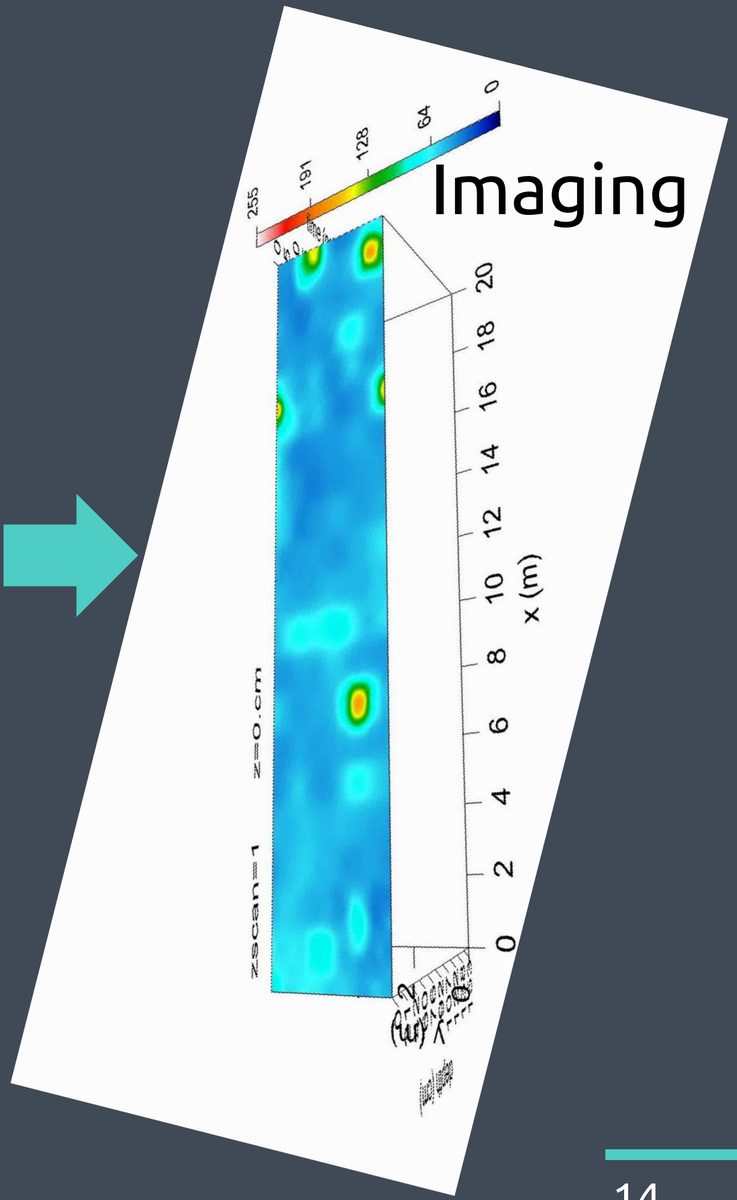
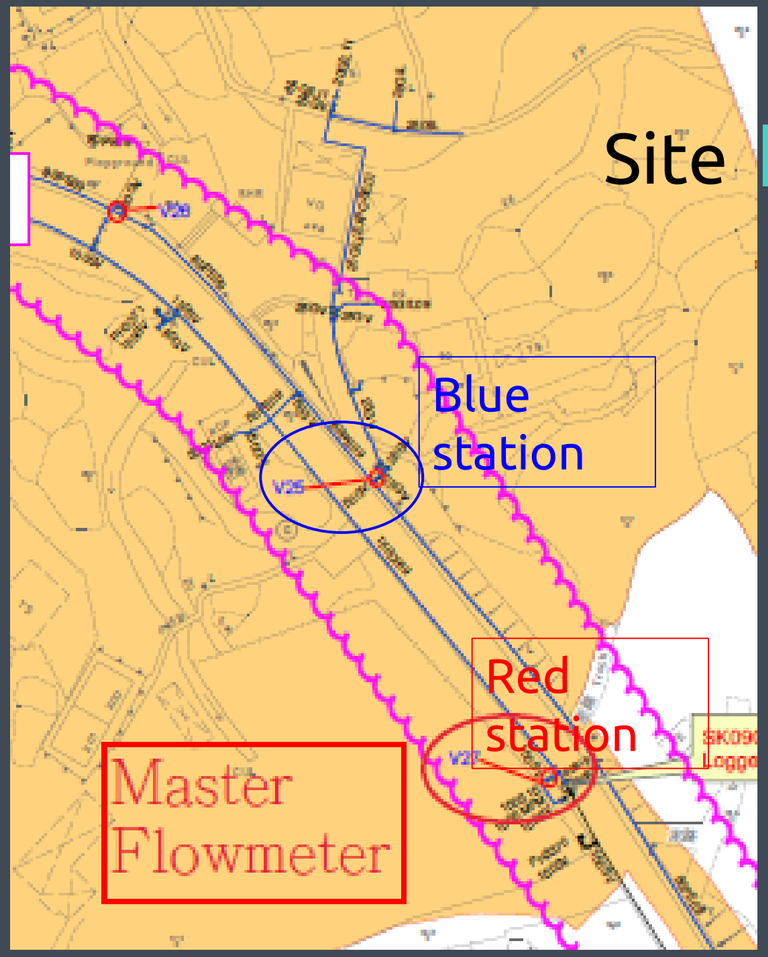


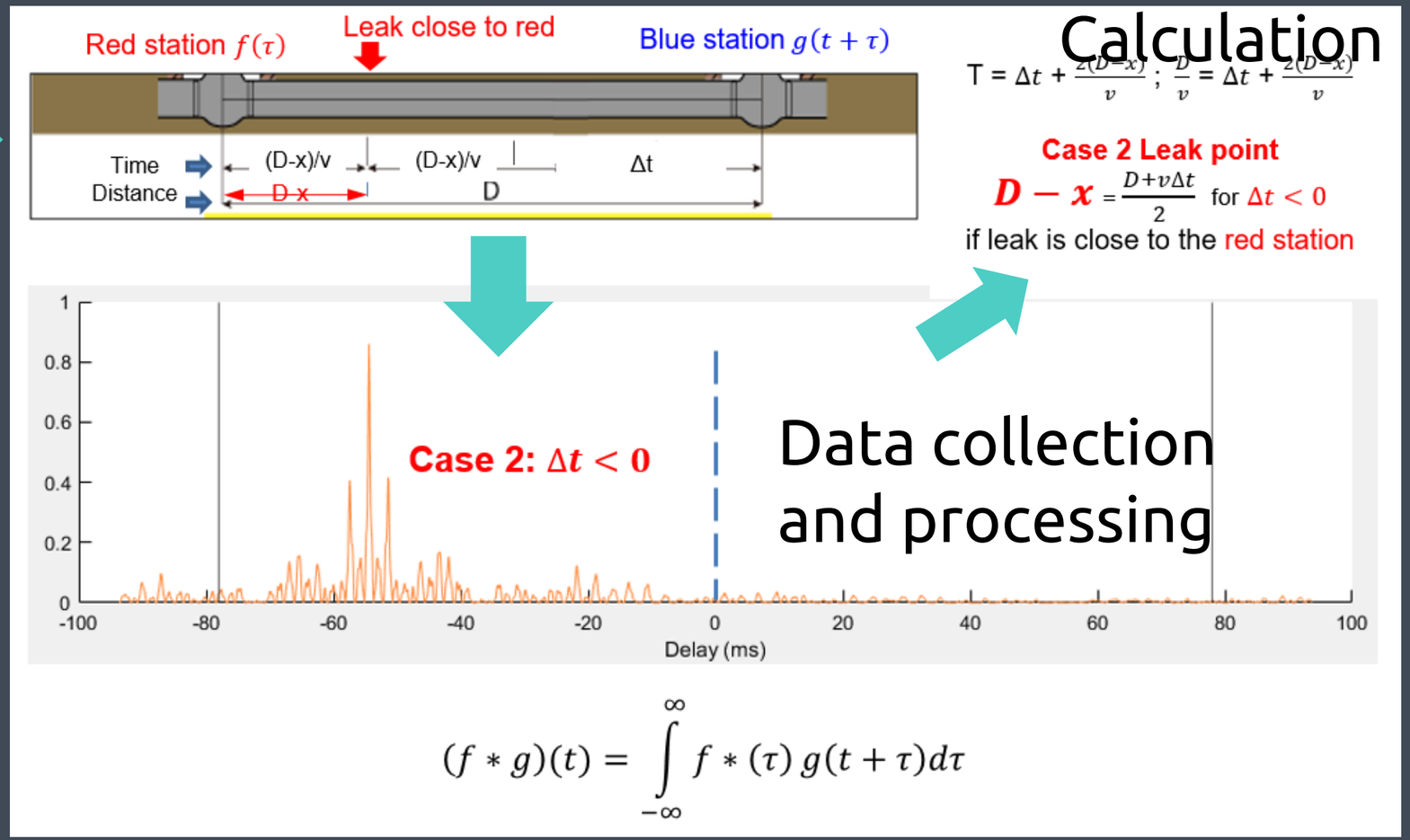
Figure 2 Standardized desktop planning of grid design and post-processing 3D imaging flow (Luo et al. 2019)



Tess X.H. Luo, Wallace W.L. Lai, Ray K.W. Chang, Dean Goodman. GPR imaging criteria, *Journal of Applied Geophysics,* 165: 37–48, 2019.

Method 法 (e.g. 2,2 Acoustic Emission for Leak Detection in pressurized water mains)





Method 法 (e.g. 1,1 PCL/EML; 1,2 GPR Accuracy)

Table 1 Recommended quality levels and accuracies of PCL/EML test/survey

Survey mode [1]	Quality level	Location accuracy [2]	
		Horizontal [3]	Vertical [4]
Active	Reliable	± 150mm or ± 15% of detected depth whichever is greater [7]	± 15% of detected depth for utility buried shallower than or equal to 3m [7]
	Survey unreliable (SU) [5]	Undefined	Undefined
	Survey not successful (SNS) [6]		
Passive	Reliable	Undefined	Undefined
	Survey unreliable (SU) [5]		
	Survey not successful (SNS) [6]		

Table 3 Recommended quality levels and accuracies of GPR test/survey

Quality level	Horizontal location accuracy [1]
Reliable	± 150mm or ± 15% of detected depth whichever is greater. This accuracy level is only valid if alignment of utility is continuously observed in C-scan.
Survey unreliable (SU) [2]	Undefined
Survey not successful (SNS) [3]	

Remarks:

[1] Accuracy levels may possibly be affected by the limitations stated in Table 2. Horizontal location refers to the centreline of the utility.

[2] A unique colour shall be used to label and annotate SU pipe/cable in drawing(s). The alignment and cover depth may be predicted from the record drawing. Reason(s) of SU shall refer to Table 2 and/or Section G Limitations.

[3] A unique colour shall be used to label and annotate SNS pipe/cable in drawing(s). The alignment and cover depth may be predicted from the record drawing. Reason(s) of SNS shall refer to Section G Limitations.

[4] If Survey Officer decides that such horizontal accuracy level cannot be reached, the suggested level of accuracy shall be suggested in the survey sheet. Reason(s) shall refer to Section G Limitations.

[5] Depth accuracy shall be derived with uncertainty models according to JCGM (2008).

Method 法 (e.g. 2,2 ALD Accuracy)

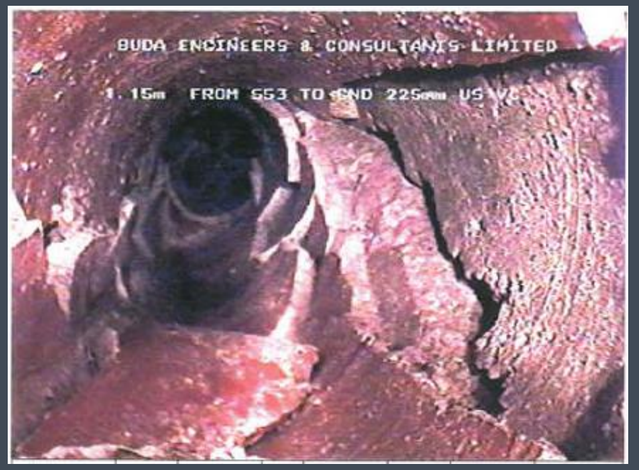
Table 1 Recommended accuracies and quality levels of leak localization, locating and pinpointing surveys using AE methods

Survey method [1]	Quality level	Horizontal locating and pinpointing accuracy[2]	Survey Condition
Method A: Noise logging	**Reliable**	NA	Utility alignment in record plan is required.
Method B: LNC and MLD/ELD	**Reliable I**: No leak	NA	Utility alignment and depth must be declared as 'reliable' according to NDTSID specification 1,1 PCL/EML (LSGI, 2019a) and/or 1,2 GPR (LSGI, 2019b)
	Reliable II: Leak	± 1.0 m or ± 0.5% of pipe distance between LNC sensors, whichever is greater at a limit agreed by the client and lab/survey company	Utility alignment and depth must be declared as 'reliable' according to NDTSID specification 1,1 PCL/EML (LSGI, 2019a) and or 1,2 GPR (LSGI, 2019b). Beyond the limit (e.g. 300m), the Signatory and the Survey Officer advise the accuracy level.
	Survey unreliable (SU)[3]	Undefined	(1) Limitations suggested in Section G, or (2) utility alignment is/are declared 'survey unreliable' or 'survey not successful'.
	Survey not successful (SNS)[4]	Undefined	Same as above.

Environment 環 (e.g. 2,1 Visual inspection)

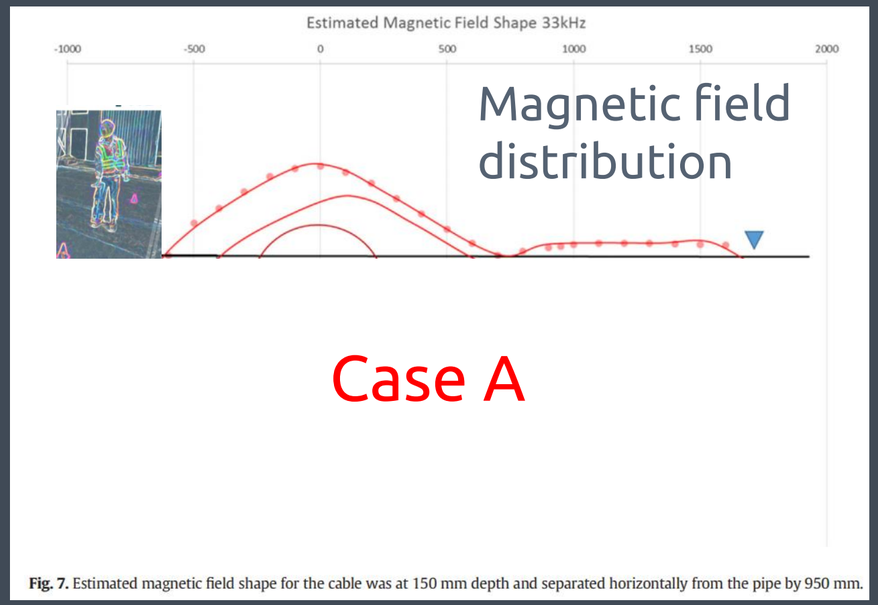
Table 4 Key points of testing and survey procedures

	CCTV survey
Maximum	< 30% for pipe diameters above 600mm.
Allowable	< 25% for pipe diameters between 300mm to 600mm.
Water Level	< 20% for pipe diameters less than 300mm.



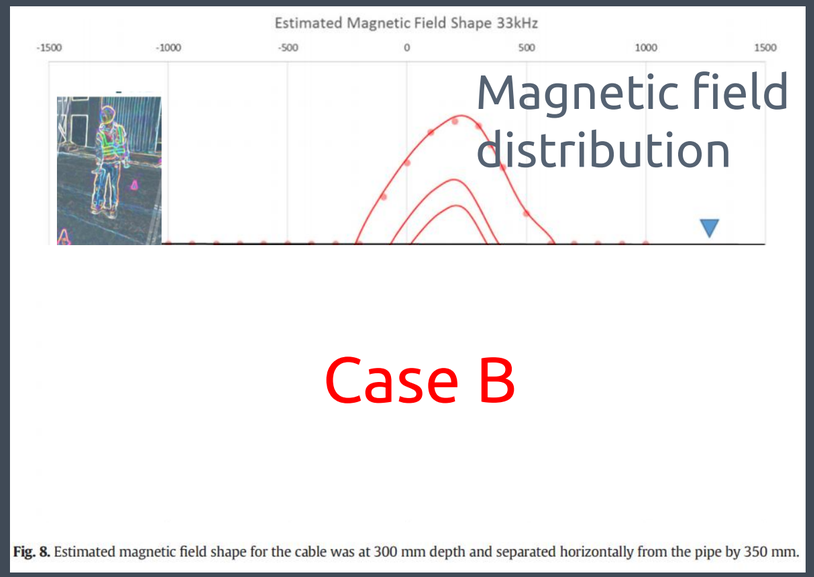
Source: HKCCEC (2009), Utility Training Institute, HK

Limitations in 4M1E (e.g. 1,1 PCL/EML)



Case A

Fig. 7. Estimated magnetic field shape for the cable was at 150 mm depth and separated horizontally from the pipe by 950 mm.



Case B

Fig. 8. Estimated magnetic field shape for the cable was at 300 mm depth and separated horizontally from the pipe by 350 mm.

K. L. Siu and Wallace W. L. Lai. A lab study of coupling effects of electromagnetic induction on underground utilities. *Journal of Applied Geophysics*, 164:26-39, 2019.

Limitations in 4M1E (e.g. 1,1 PCL/EML)

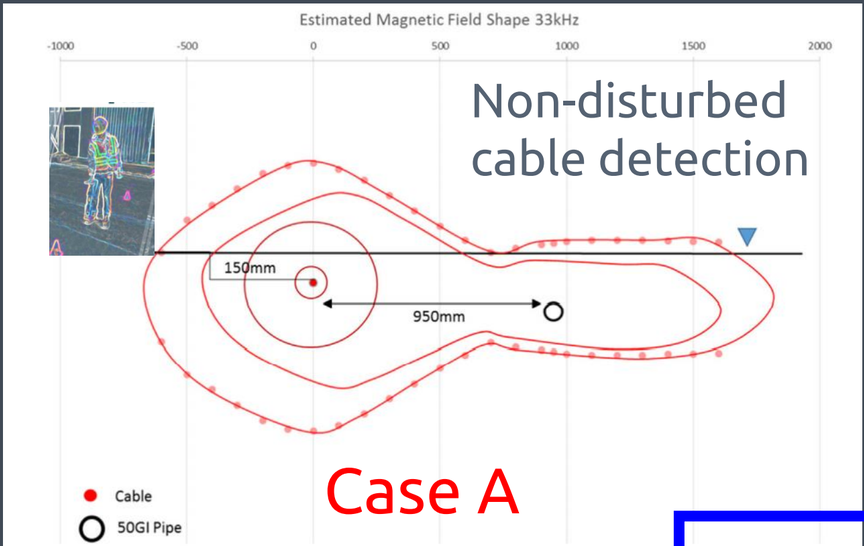


Fig. 7. Estimated magnetic field shape for the cable was at 150 mm depth and separated horizontally from the pipe by 950 mm.

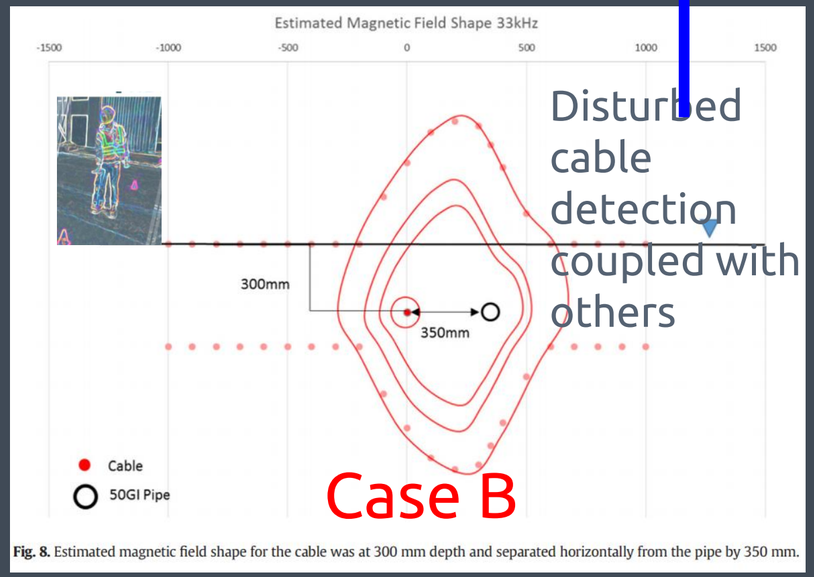


Fig. 8. Estimated magnetic field shape for the cable was at 300 mm depth and separated horizontally from the pipe by 350 mm.

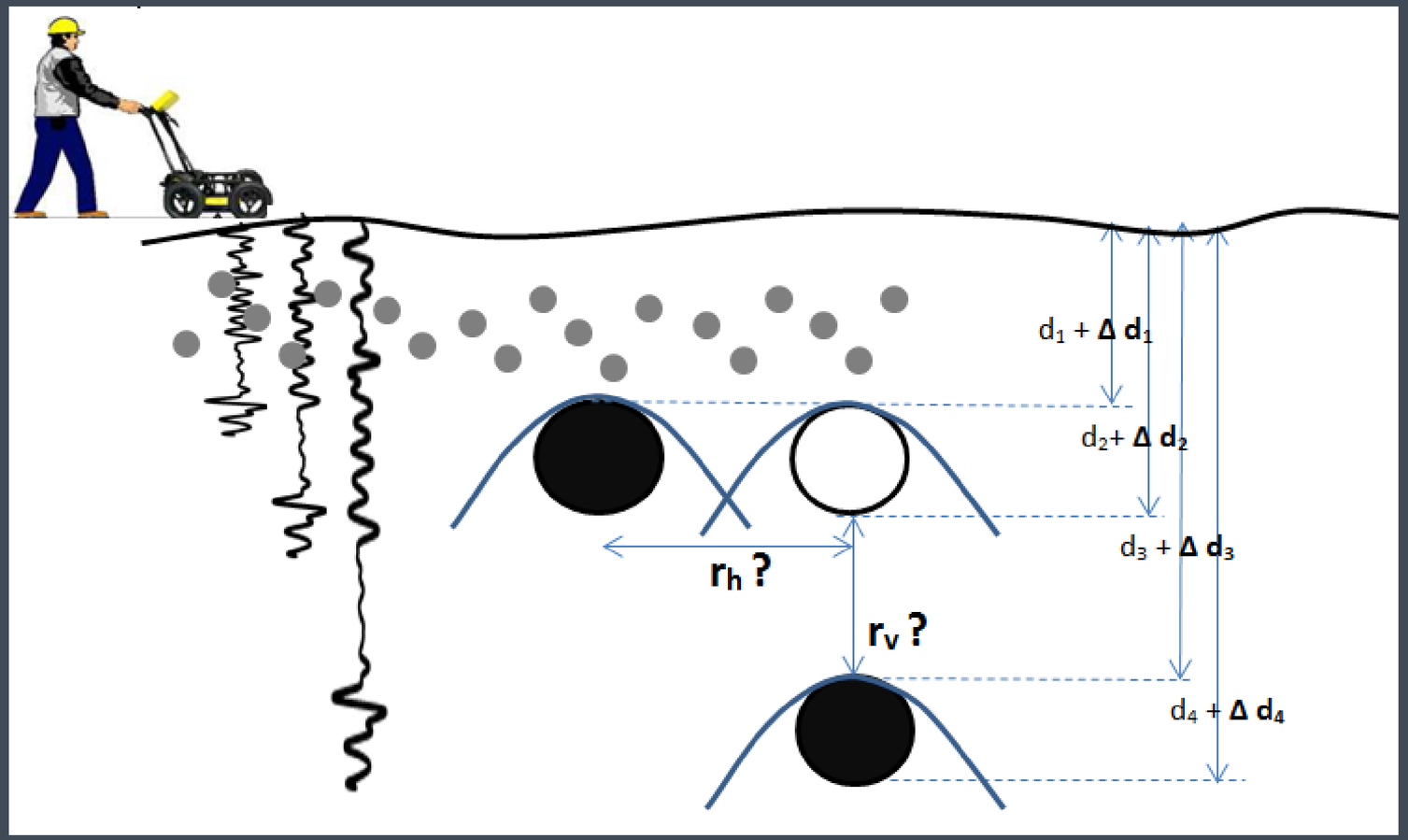
Table 5 Limitations of PCL/EML Survey

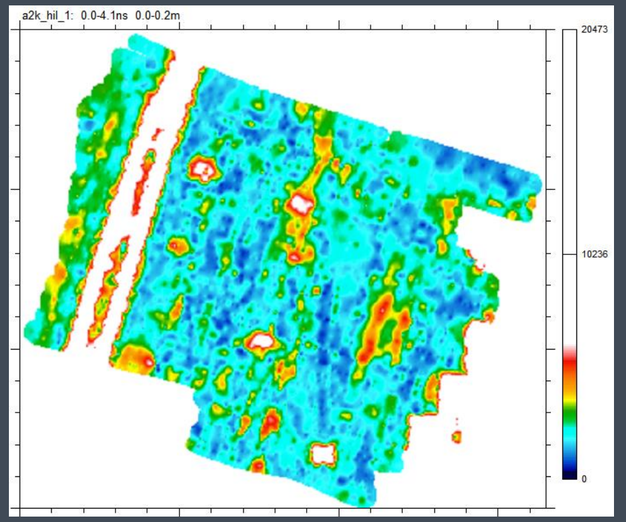
Limitations	Examples	Reasons of declaring 'Survey Unreliable'	Reasons of declaring 'Survey not Successful'
A. Coupling effects of nearby utilities	Pipes or cables are buried in the same lateral or vertical level and are very close to each other, or close to a 90° vertical and horizontal bend, or junctions. These common scenarios make tracing of individual pipes or cables unrealistic and reduce resolution because of the interference of coupled magnetic fields with similar field strength on parallel/nearby utilities (Siu and Lai, 2019). The Survey Officer shall declare and record on-site such coupling effects as 'survey unreliable' or 'survey not successful'. For example, when the armour layer/shield of the target cable is isolated from the connected earthing point, signal is diverted and coupled to other cables connected to the same earthing points of the target cable.	Applicable	Applicable
B. Record drawings	Utility information is not available or incomplete or is in general inaccurate	Applicable	Applicable
C. Lack of closed loop for signal propagation	A closed loop through the target pipe or cable may not be formed causing only a weak signal to be propagated. For example, (1) the armour layer/shield of the target cable is only earthed at one side; (2) the armour layer/shield of the target cable is not connected when cables are joined. It is more likely to happen for optical fibre cables and less likely to happen for telephone cables.	Applicable	Applicable

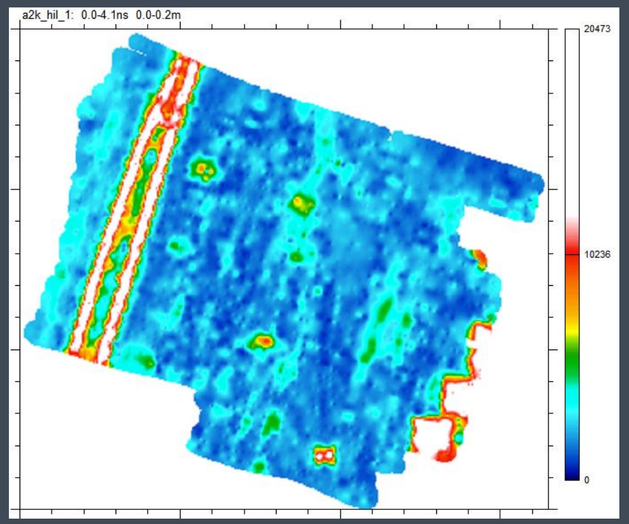
D. Depth range limits
E. Site constraints
F. Pipe size restrictions
G. Material
H. Under construction

Limitations in 4M1E – GPR

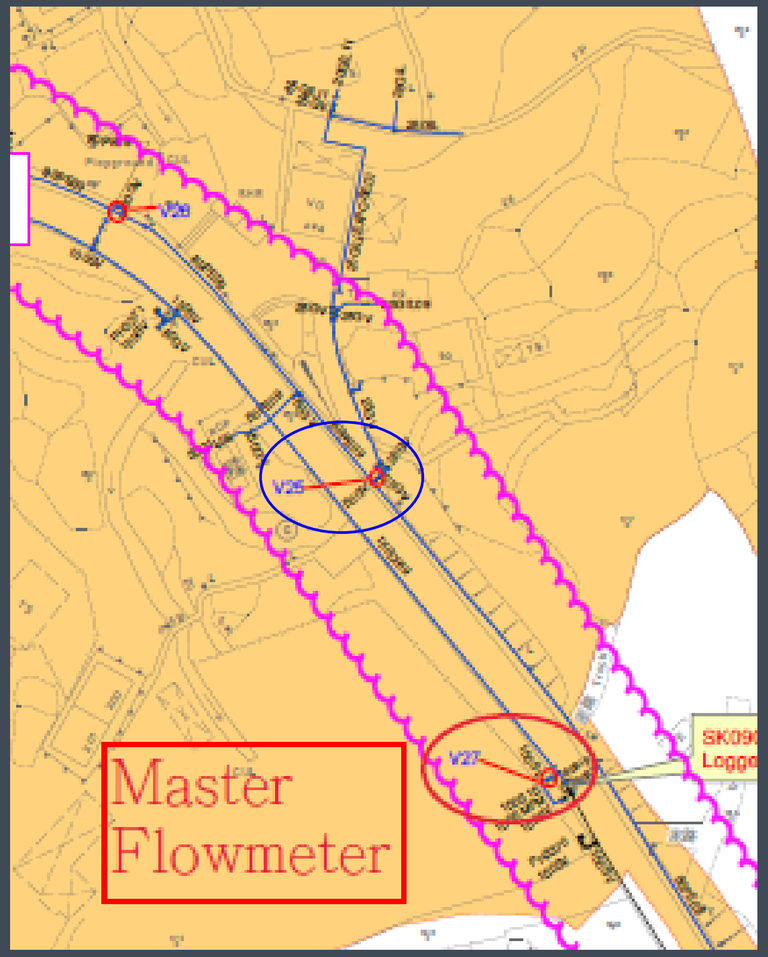
Frequency and depth? Resolution?
Scattering? Near/far-field? Uncertainties?

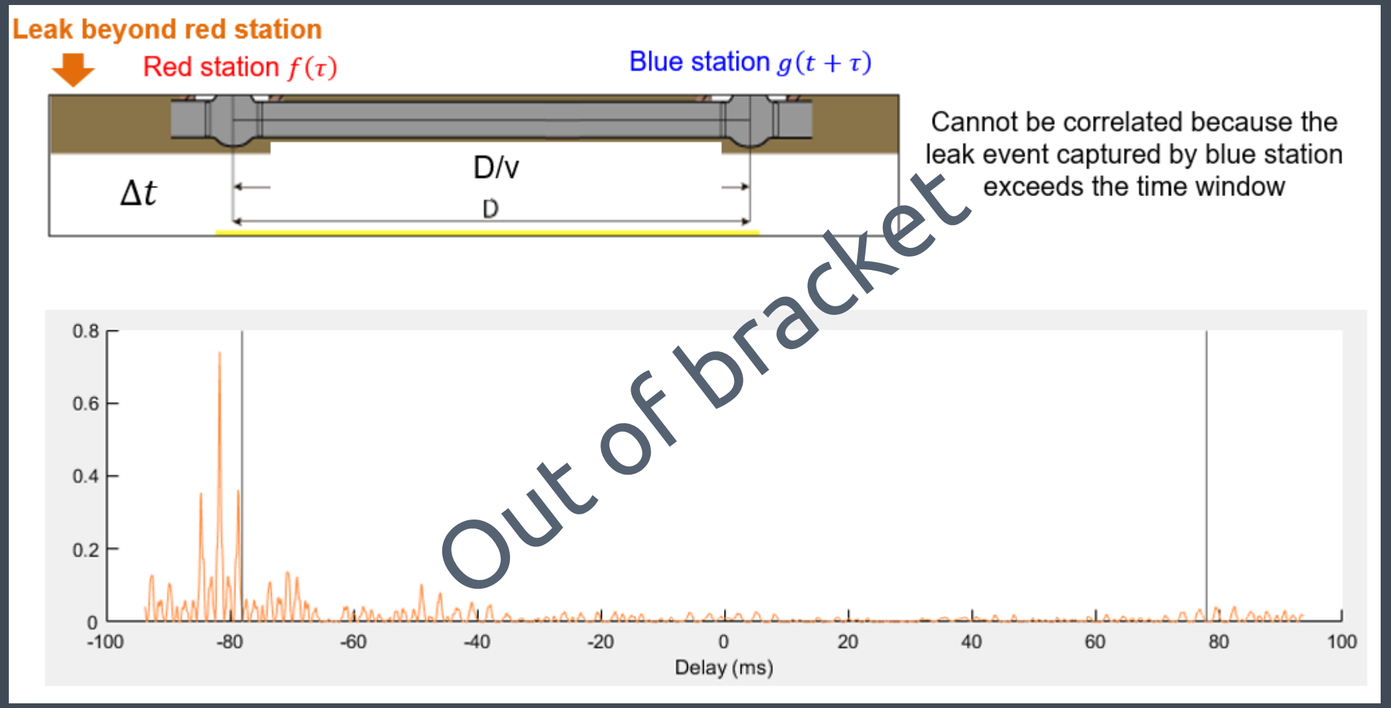






Limitations in 4M1E – Acoustic Leak Detection





How can Technologies of Nondestructive Utility Survey be Standardized in Specifications?

Is that all ??? What is the next step?

A typical office and witness assessment in an on-site visit

Morning

Technical assessor check **personnel, equipment, materials and procedure** related to the tests. Approved signatory and test operators are required to demo upon request.

Lead assessor check quality assurance (O-chart, training record, calibration certificate) check by lead assessor

Afternoon

Interview of **approved signatory** and **test operators**

Private discussion between the lead and technical (3rd party) assessors

An example of Non-conformance (NC) for assessment in spec 1,1 PCl/EML

Two questions would be raised in this demonstration of **Pipe Cable Locator (PCL)** during on-site assessment.

1. Which part(s) of 4M1E is/are not conformed, and under which clause?

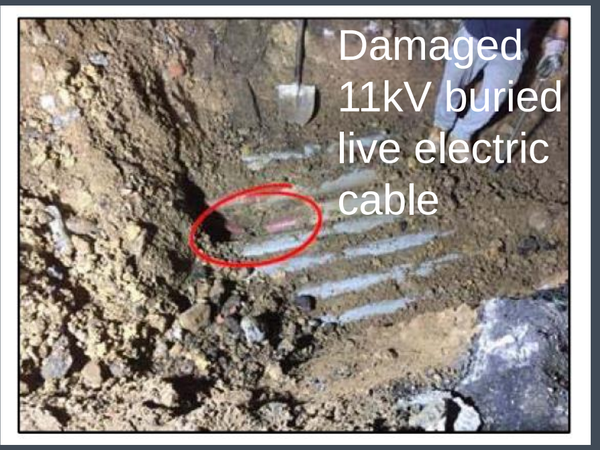
2. Grading of NC or observations

- Observations?
- Minor non-conformance (NC)?
- Significant non-conformance (NC)?
- Critical non-conformance (NC)?

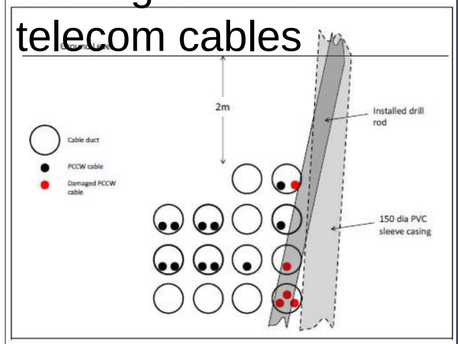
Accidents about UU :

Can the spec and HOKLAS accreditation help?

Bursting of WSD dia. 450 mm Fresh Water main



Damaged PVC telecom cables

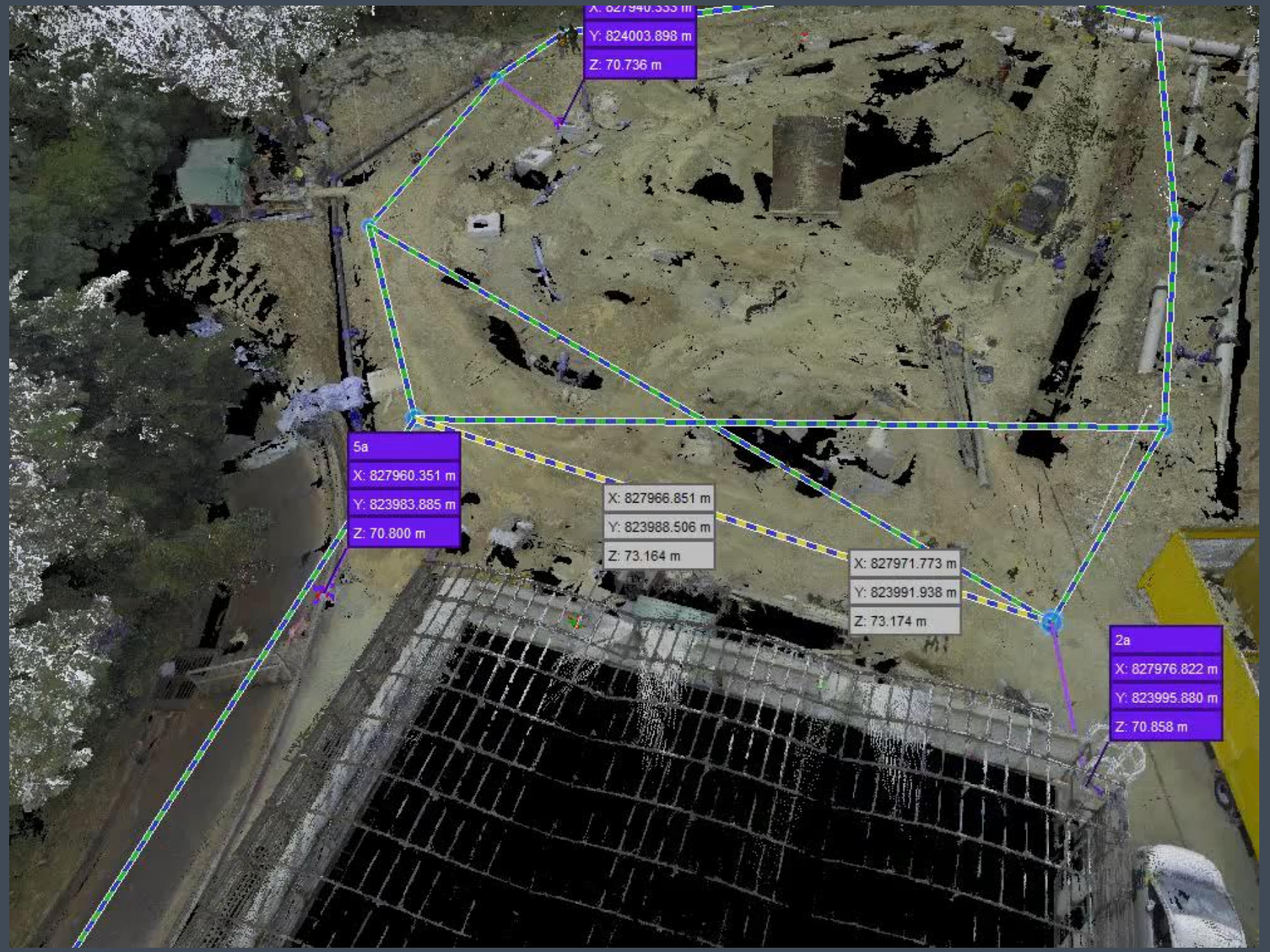


Reasons: Implementation of Permit to work/dig, slant drill bit, unknown alignment of a pressurized main during road re-surfacing, CP's competency…. (Source: MTR)

Training and validation

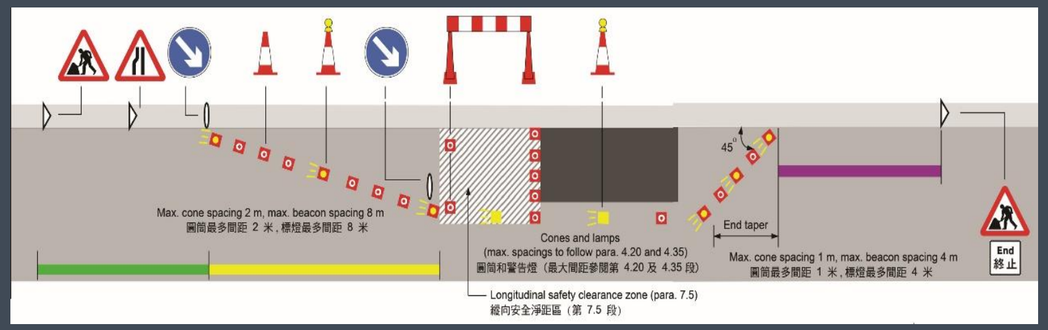
- PolyU LSGI and Black & Veatch’s design of a 19000 sq. ft training ground of U/G water leak detection for WSD in Tsing Yi
- Construction to be finished by Q1 2021.

Training and validation

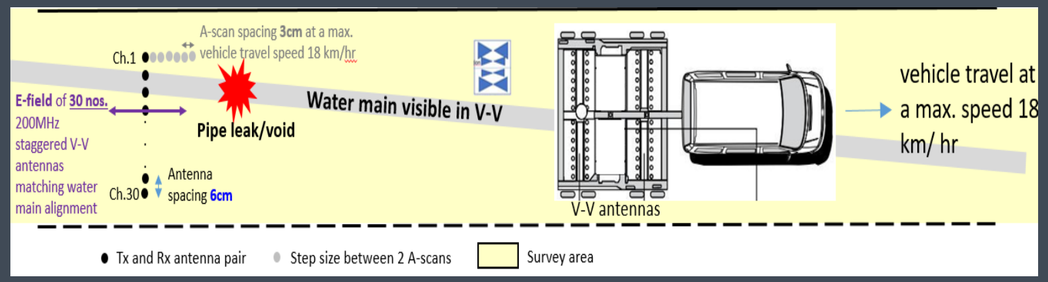


Laser scans of as-built records of utilities

Latest work (multi-channel GPR surfing in highway speed)



vs



Arriving to PolyU in January 2021

Utility Research and consultancy in PolyU

Ground Penetrating Radar
- Algorithms of velocity in materials (Janet)
- Leak/void diagnosis (Tess, Bella, Yimin)
- Multi-channel full coverage imaging and diagnosis (Ray, Sabi, Yimin)
- Uncertainty Analysis due to water distribution and scattering (Frank, Rex)
- Standardization of 3D imaging and image matching (Tess)
- Robot-driven GPR for full-scale 3D imaging (Ray, Nelson)
- Corrosion of steel bars in concrete (Phoebe)
- GPR psychology (Bella)

Infrared thermography
- Pipewall composite diagnosis (Janet, Samuel)
- External wall composite diagnosis and BIM (Lydia)
- Active/passive thermography algorithms (Janet, Samuel)

Let's fly
- Drone IR and laser scanning for as-built information (Sahib, Nelson, Ray)

Acoustic emission for leak detection
- Ground-based noise logging and leak noise correlation algorithms and applications (Ray, Sahib, Bella)
- Leak detection and AI via in-pipe survey with acoustic sensors with high-pressure water flow (Ray, Sahib, Bella)

http://www.lsgi.polyu.edu.hk/academic_staff/Wallace/index.html

Acknowledgement (committee members of the six specifications)

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Lo King-Yin, Victor (Chairman, Civil Discipline Advisory Panel and Past Chairman of Civil Division of HKIE)
Wong Kin-Yan, Samson (Former Senior Accreditation Officer of Hong Kong Accreditation Services)

Bob Wilson (EGS (Asia) Ltd.)
Chan Yuen-Lok (The Hong Kong and China Gas Company)
Chiu Sing-Kit (Hong Kong Telecommunication (HKT) Ltd.)
Fung Yuk-Lun, George (MTR Corporation Ltd.)
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Kung Hiu-Leung, Daniel (HKIUS)
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Lai Mei-Yee (Leica Geosystem Ltd.)
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Yuen Chun-Ning, Augustine and Ip Lydia (Xylem (Hong Kong) Ltd.

Take-home message

- 4M1E does not guarantee all survey results are correct but the process of accreditation contributes to making sure qualified people doing reasonable things.

- Procurement stage:

1. Identify the most related PolyU LSGI's UU specifications in the required scope of service
2. Include the specification as part of contract document
3. Award contract to those accredited service providers/lab

- Monitoring stage:

1. use the accuracy table in the specifications as a guideline.
2. recognize and refer to the limitations in the specifications as a guideline.
3. use the report section of the specifications as required deliverables of services.

“Make the invisible visible”

Thank you!

Any questions?

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