ISSN 2029-6991 / eISSN 2029-7009

GEODESY and CARTOGRAPHY

2025
Volume 51
Issue 4
Pages 204–215
https://doi.org/10.3846/gac.2025.21838

UDC 528.918

DEVELOPING STANDARDS FOR SURVEYING, MEASURING, AND MAPPING UNDERGROUND OBJECTS USING THE GPR METHOD FOR VIETNAM

Phi Son NGUYEN, Thanh Thuy NGUYEN✉, Ngoc Long DAO, Chi Thinh LE, Thi Hue NGUYEN

The Viet Nam Institute of Surveying and Mapping, Hanoi, Vietnam[#]

Article History:
- received 11 July 2024
- accepted 09 September 2025

Abstract. In the context of rapid urbanization, detailed investigation of underground objects in the shallow layer is very important for safe and efficient urban planning, construction, and operation. With many outstanding advantages, Ground Penetrating Radar (GPR) technology has been increasingly applied worldwide in shallow geophysical surveys. However, in Vietnam, applying GPR for surveying and measuring objects in the above spatial range is only in its early stages, and there are no official standards or regulations. This paper uses the GPR method to develop technical standards for investigating and mapping underground objects within 0–6 m depth. The research methodology includes synthesis analysis of international standards, expert consultation, and field experiments. The main results of the study include: (1) Proposing a 9-step detailed GPR survey process; (2) Specific technical regulations for GPR survey work; (3) Classification of 4 quality levels of products (QLB1-QLB4) with specific requirements; (4) Guidelines for representing and presenting maps of underground objects. This standard will be the first document to standardize the application of GPR in measuring and acquiring information on underground objects in Vietnam, contributing to promoting the widespread application of GPR technology in practice.

Keywords: standard, GPR, object, underground, shallow layer, map.

✉Corresponding author. E-mail: ***ntthuydostic@gmail.com***
[#] The Spatial Data Institute (SDI), Hanoi, Vietnam

1. Introduction

1.1. Importance of surveying underground objects in the shallow layer for urban development

In recent years, along with the rapid development of cities, the increasing demand for land use has led to urban underground space being increasingly exploited and installed with many technical infrastructure systems such as water supply and drainage pipelines, power cables, telecommunication cables, lighting systems, transportation, etc. These are important "arteries" for the development of cities. However, the management, exploitation, and protection of these underground technical infrastructure works face many challenges due to the lack of complete and accurate information about their location, status, and depth.

On the other hand, the increase in construction activities on the ground also poses potential risks of affecting and damaging underground structures. In reality, accidents due to the rupture of underground pipelines and cables cause traffic insecurity, flooding, and power outages, which occur quite commonly, causing great damage to people and property. The main reason is that underground works are not mapped and accurately located, or information about them is not updated and complete. Therefore, measuring and mapping to update the current status of underground objects and works is extremely urgent.

1.2. Introduction to GPR technology and applications

Ground Penetrating Radar (GPR) is a non-destructive geophysical method that uses high-frequency electromagnetic waves to detect and locate objects underground. The operating principle of GPR is based on emitting and receiving radar waves reflected from physical boundaries in the ground.

In recent years, modern non-destructive measurement technologies such as GPR have been widely applied in surveying and measuring underground works, thanks to the ability to accurately determine the location depth and detect abnormalities of underground structures without affecting the structure above. GPR measurement results provide a detailed 3D image of underground objects in an intuitive way. This helps create highly accurate underground infrastructure maps, meeting the requirements of safe and efficient management and operation.

Globally, GPR has been widely applied in many fields, such as archeology, engineering geology, environment, construction, and infrastructure management. In Vietnam, GPR is gradually being applied in urban underground infrastructure surveys but is still limited compared to the application potential of this technology.

1.3. Current status of GPR technology application in Vietnam

In Vietnam, applying GPR in surveying and mapping underground objects is only in its initial stage. Some projects and studies have experimented with using GPR, but there are still many limitations:

- Lack of standardized technical procedures for GPR survey and data processing.
- No standards on accuracy and technical requirements for underground object map products.
- Lack of specific guidelines on representing underground objects on maps.
- No regulations on the quality assessment of GPR survey results.

These limitations lead to inconsistent and ineffective application of GPR, causing difficulties in comparing and integrating results between different projects.

1.4. Research objectives and scope

Based on the above situation, this paper aims to develop a comprehensive technical standard for surveying, measuring and mapping underground objects within the shallow layer (0–6 m) using the GPR method in Vietnam.

The scope of the research includes:

- Underground objects within 0–6 m depth below ground.
- Urban underground technical infrastructure works and natural objects.
- Technical process from field survey to data processing and map creation.

This standard aims to provide a unified legal and technical framework, creating a basis for the widespread and effective application of GPR technology in the mapping field in Vietnam.

2. Data and methods

2.1. Research data

Documents, studies, and regulations on underground works and GPR application potential in detection and mapping by domestic and foreign authors: Notable studies include Stokes et al. (2002) on tree root mapping using GPR, Ji et al. (2009) on mine and bomb detection using GPR, Strange and Yelf (2012) on real-time GPR determination, Utsi (2014) on fiber optic cable detection... In Vietnam, studies by Trần (2011, 2012), on underground works detection using Ramac X3M GPR and solutions to improve efficiency, Nguyễn et al. (2023) on GPR application in shallow geological research, Nguyễn et al. (2021) on the technological process to determine underground discharge objects using GPR...

Related legal documents, standards, and technical regulations of Vietnam, such as: Decree 39/2010/ND-CP on the management of urban underground construction space, Law on Surveying and Mapping 2018, Vietnam Building Code QCVN 07:2016 on underground technical infrastructure works (water supply, drainage, electricity, telecommunications, fuel supply, gas...), National standard on Georadar method TCVN 9426:2012, Circular 68/2015/TT-BTNMT on technical regulations for direct topographic measurement (Bộ Xây dựng, 2016a, 2016b, 2016c, 2016d, 2016e, 2016f, 2016g, 2016h; Tổng Cục Địa chất và Khoáng sản, 2012).

Related international guidelines, technical specifications, and standards such as: Guidelines on underground utility mapping standards of Malaysia (AM/FM Technical Sub-Committee, & National Mapping and Spatial Data Committee, 2006); PAS 128:2014 standard of the UK on detection, verification, and location of underground utilities (Institution of Civil Engineers, 2014); ASTM D6432 standard of USA on using GPR method in subsurface investigation (American Society for Testing and Materials [ASTM], 1999); ASCE 38 standard of USA on collecting and depicting existing subsurface utility data (American Society of Civil Engineers [ASCE], 2002, 2022); AS 5488 standard of Australia on location and classification of subsurface utilities (Bennett, 2023; Engineering Education Australia, 2023; Butler, 2019); CJJ 61-2017 standard of China on urban underground pipeline survey and mapping techniques (Beijing Surveying Design Institute, 2017)...

Experimental survey data using RIS MF HI-MOD GPR equipment from projects and tasks of the Institute of Geodesy and Cartography such as Formosa Ha Tinh, Lee & Man Vietnam paper mill, AB Mauri La Nga... Data includes raw files, processed files, 2D cross-sections of GPR scan lines, coordinates and elevations of control points, scan points, field photos, and resulting maps.

2.2. Research methods

This paper uses a combination of several methods to develop the standard in survey, measurement, and mapping of underground objects in the shallow layer, using the GeoRadar method. The main methods include:

2.2.1. Method of inheriting and synthesizing documents

This method collects, analyzes, and evaluates studies and standards related to GPR application in shallow engineering-geological surveys. Specifically:

- Studying domestic works: Analyzing GPR test results of Vietnam Geological Survey and other scientific studies to assess the current situation and draw lessons from GPR application in Vietnam.

- Synthesizing international studies: Analyzing reputable international research works to grasp the principles, techniques, and latest development trends of GPR technology.
- Evaluating international standards: Detailed study of standards such as ASTM D6432-11 (USA), PAS 128:2014 (UK), and CJJ 61-2017 (China) to compare, cross-reference, and selectively inherit contents suitable for Vietnam's conditions.

The documents are analyzed and compared to identify appropriate contents that can be applied to Vietnam's conditions and identify gaps that need to be supplemented in the new standard.

2.2.2. Expert consultation method

This method is applied through workshops, seminars, and direct consultations with reputable experts and managers in engineering geology, GPR technology, and mapping. The main purposes are:

- Collecting evaluation opinions on the studied and proposed standards and technical criteria.
- Create a forum for experts to exchange and discuss each specific content of the draft standard in detail.
- Identifying remaining issues and proposing solutions.

Expert opinions are synthesized and classified according to specific issues, such as survey object lists, quality levels, and technical processes for easy processing and integration into the draft standard.

2.2.3. Analysis and synthesis method

The study conducts detailed analysis and comparison of related international standards such as: Guidelines on underground utility mapping standards of Malaysia (2006); PAS 128:2014 standard of UK; ASTM D6432 standard of USA (1999, 2011, 2019 versions); ASCE 38-02 and ASCE 38-22 standards of USA; AS 5488 standard of Australia (2013, 2019, 2022 versions); CJJ 61-2017 standard of China, studies, projects, GPR survey tasks in Vietnam.

The analysis focuses on each standard's structure, content, advantages, and disadvantages and assesses its applicability in Vietnam. The results of this step help identify contents that need to be inherited and adjusted to suit Vietnam's conditions.

2.2.4. Modeling method

This method is applied to:

- Develop a 9-step detailed GPR survey, measurement, and mapping process, clarifying the sequence and content of each step.
- Design sample map forms, field books, and reports illustrating the products of each step in the process.
- Express the provisions in the standard by models, diagrams, and visual tables for easy understanding and application.

The results of this method help concretize technical regulations and create tools to support the application of standards in practice.

3. Results and discussion

3.1. List of underground objects in the shallow layer

Based on the synthesis from international studies and standards on the classification of underground technical infrastructure and underground works mentioned above and an actual survey of underground objects in the shallow layer in Vietnam, this study proposes to identify eight main groups of objects that need to be surveyed by GPR within the shallow layer (0–6 m) including: discharge works, water supply and drainage, energy, electricity, telecommunications, chemicals, tunnels/technical trenches and natural object groups. Specifically, there are eight groups with 31 types of underground objects, as presented in Table 1 below.

Table 1. List of underground objects in the shallow layer in Vietnam

No.	Object group	Underground objects
1	Water Supply	Underground water supply pipeline
		Groundwater extraction wells
		Groundwater level monitoring well
		Underground clean water storage tank
		Surface exposure points of water supply objects (Water valves, Water technical chambers, Exposed water technical chamber points, Fire hydrants)
2	Drainage	Wastewater drainage pipeline
		Rainwater drainage culvert, combined sewer
		Wastewater drainage culvert
		Underground wastewater settling tank
		Surface exposure points of drainage objects (Exposed connection points and wastewater collection points...)
3	Energy	Pipeline for gasoline, oil, gas, hot steam, hot water
		Surface exposure points, markers, valves, and meters for gasoline, oil, gas, hot steam, and hot water pipelines
4	Electricity	Underground power line
		Power cable conduit
		Surface exposure points of electrical objects, transformer stations, power cable markers
5	Telecommunications	Telecommunication cable
		Telecommunication cable conduit
		Surface exposure points of telecommunication objects, telecommunication cable markers
6	Chemicals	Chemical pipeline
		Storage tank
		Surface exposure points of chemical objects, markers, valves, meters of chemical pipelines

End of Table 1

No.	Object group	Underground objects
7	Tunnels, trenches, culverts, technical chambers	Technical tunnel
		Technical trench
		Technical culvert
		Technical chamber
8	Natural objects	Water pockets, water lenses
		Cracks, voids, karst holes
		Artificial holes

This list is based on analyzing and synthesizing research documents, consulting expert opinions, and discussing with relevant agencies. These are important, common objects in the shallow underground layer in Vietnam and can be detected and mapped using the GPR method. This list will serve as a basis for planning, designing surveys, and representing content on maps of underground objects.

Compared to international standards, this list has added a group of natural objects suitable for diverse geological conditions; detailed types of water supply and drainage works, reflecting the characteristics of urban infrastructure systems; limited survey depth within the 0–6 m range, suitable for the capability of popular GPR equipment in Vietnam.

3.2. Analysis of factors affecting the ability to detect and interpret objects by GPR

There are three factors influencing the choice of antenna frequency: (1) Estimated depth of potentially distributed objects (can be referenced from existing plans or as-built documents); (2) Estimated size of objects to be scanned (refer to documents or exposed connection points); (3) Heterogeneity of soil and rock in the shallow layer (refer to borehole data – if available).

Regarding the equation for calculating the frequency of each influencing factor, f_C^D, f_C^R, f_C^C are calculated according to Equations (1) to (3) below. Then, the center frequency to be used f_C must meet the criteria presented in expression (4) within the range between f_C^D, f_C^R, f_C^C. If this criterion cannot be met, GPR technology cannot detect the object, and other methods need to be considered.

$$f_C^D = \frac{1200\sqrt{\varepsilon' - 1}}{D} \text{ (MHz)}; \tag{1}$$

$$f_C^R = \frac{75}{\Delta s\sqrt{\varepsilon'}} \text{ (MHz)}; \tag{2}$$

$$f_C^C = \frac{30}{\Delta L\sqrt{\varepsilon'}} \text{ (MHz)}; \tag{3}$$

$$f_C : f_C^R < f_C < \min\left(f_C^D, f_C^C\right). \tag{4}$$

This equation allows balancing between resolution requirements and survey depth, suitable for soil and rock types, expected size, and material of objects to be detected. Proper selection of antenna frequency will decisively affect the detectability and quality of GPR images obtained.

Additionally, it is important to note that while antenna frequency is crucial in determining planar positioning accuracy, other factors, such as depth penetration and resolution, also play significant roles. The choice of antenna frequency involves a trade-off between resolution and depth penetration capabilities. Higher frequencies provide better resolution but limited depth penetration, while lower frequencies allow for greater depth penetration but with reduced resolution. This balance is critical in achieving optimal accuracy in the planar positioning of underground objects across various environmental conditions and object characteristics.

3.3. Regulations on geodetic work and survey design

Regarding establishing a geodetic control network to position GPR to scan lines and points, the standard inherits existing regulations in Circular 68/2015/TT-BTNMT on building coordinate networks, elevation networks, and corresponding positioning methods for each control network class.

Regarding the content and technical requirements of field survey work, the standard stipulates including a preliminary survey and analysis of documents related to the survey area; field survey to identify exposed connection points of structures, take photos, sketch; survey of soil and rock environment and hydrological conditions to select scanning parameters; GPS positioning of characteristic points...

Regarding the GPR measurement layout design: The scanning grid layout is designed based on the preliminary survey results and is suitable for terrain, topographic conditions, and distribution of underground objects. The square grid size depends on the antenna size to ensure full coverage of the scanning area. Do not design grids for areas with fixed topography, complex terrain, or restricted or dangerous areas. Each scan line is assigned a separate number and has an appropriate direction to optimize scanning efficiency.

3.4. Regulations on four levels of positioning accuracy according to quality levels

Based on analysis of criteria on horizontal positioning accuracy and depth in international standards of Malaysia, the UK, Australia, and the USA combined with research results on the influence of equipment characteristics, environment, depth... on GPR effectiveness, the standard proposes to divide into four quality levels from high to low as QLB1, QLB2, QLB3, QLB4 with corresponding requirements on horizontal positioning accuracy and depth as shown in Table 2.

The clear stipulation of these accuracy levels is suitable for GPR application conditions in Vietnam, creating criteria for evaluating survey product quality and requirements on the level of detail when represented on maps.

Table 2. Proposed regulations on positioning accuracy levels according to quality levels for Vietnam

Quality level	Horizontal accuracy	Depth accuracy	Supporting data
QLB1	≤ ±15 cm	≤ ±15% of depth	The object's horizontal position and depth are detected by multiple techniques, such as combining GPR and EML techniques
QLB2	≤ ±25 cm	≤ ±40% of depth	The object's horizontal position and depth are detected by the GPR technique combined with another geophysical technique
QLB3	≤ ±50 cm	Not determined	The GPR technique combined with another geophysical technique only detects the object's horizontal position
QLB4	Not determined	Not determined	An object or part of an object is suspected to exist but has not been identified or interpreted, thus represented as an estimate

3.5. Regulations on principles of content representation and presentation of shallow layer object maps

Regarding layout presentation (Figure 1), the standard stipulates that the map includes a heading at the top with the map name and survey area name. The main content section shows objects with symbols and legends at the bottom. Use the national coordinate system VN-2000 to show the position of objects.

Regarding content representation regulations, the standard is divided into eight main object groups, as in Table 1 above. Each object is represented by a point, line, or area symbol combined with the legend on mandatory attributes such as position, material, size, and function. The symbols (in Table 3) follow the principle of hierarchical representation according to 4 levels: scale, half-scale, non-scale, and annotation. The display order is prioritized according to the importance and current use of the objects.

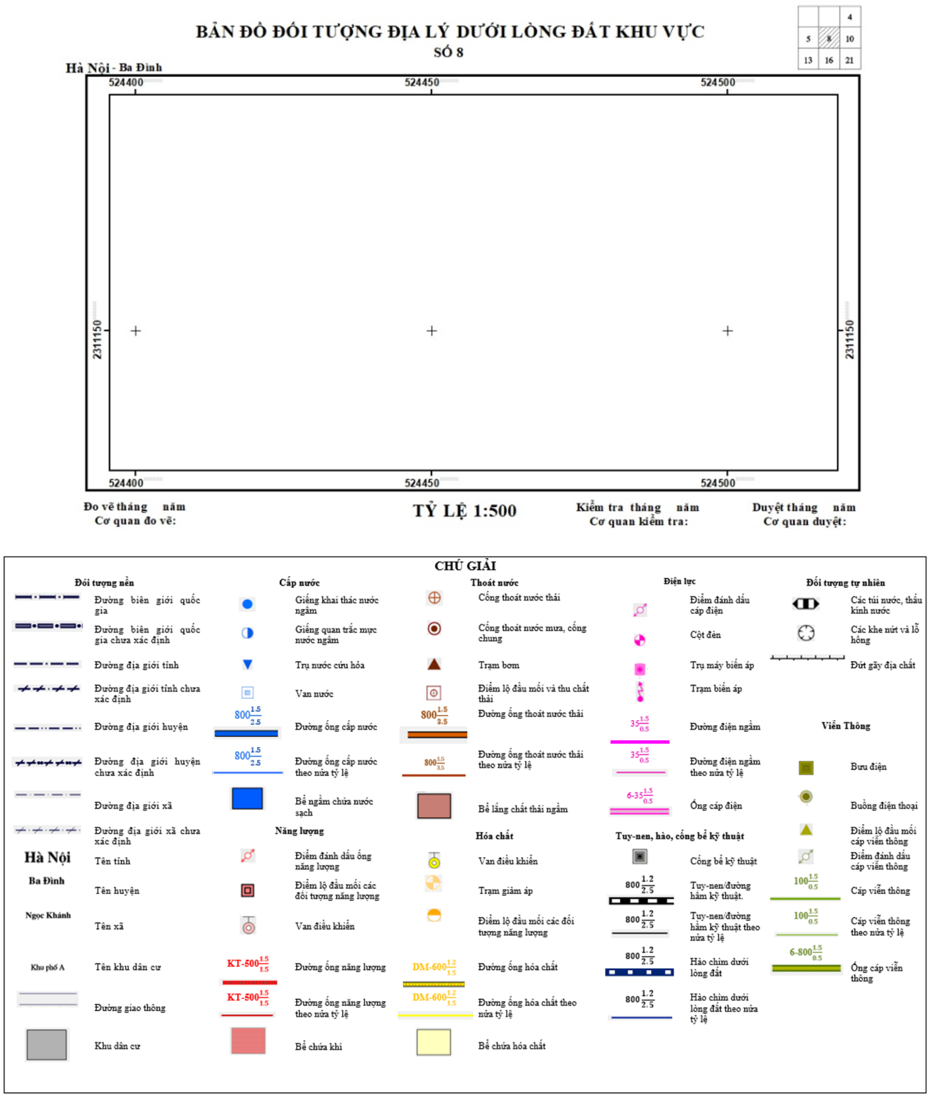
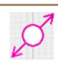
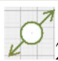


Figure 1. Proposed layout of the underground objects in the shallow layer for Vietnam

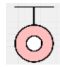
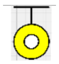
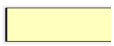
Table 3. Proposed regulations on symbols of objects on underground object maps for Vietnam

No.	Object		Object type	Symbol 1:200. 1:500. 1:1000. 1:2000	Color R	Color G	Color B	Explanation
1	Boundary objects							
1.1	National border		Line	1.0	0	0	0	
1.2	Unidentified national border		Line	1.0	0	0	0	
1.3	Provincial border		Line	0.5	0	0	0	
1.4	Unidentified provincial border		Line	0.5	0	0	0	
1.5	District border		Line	0.4	0	0	0	
1.6	Unidentified district border		Line	0.4	0	0	0	
1.7	Commune border		Line	0.2	0	0	0	
1.8	Unidentified commune border		Line	0.2	0	0	0	
1.9	Province name			**Hà Nội**	0	0	0	Time New RomanB,20
1.10	District name			**Ba Đình**	0	0	0	Time New RomanB,16
1.11	Commune name			**Ngọc Khánh**	0	0	0	Time New RomanB,13
1.12	Residential area name			**Khu phố A**	0	0	0	Time New Roman,12
1.13	Transportation route		Line	0.2	0	0	0	
1.14	Residential area		Fill		204	204	204	
2	Underground objects in the shallow layer							
2.1	Water supply	Groundwater extraction wells	Point	2.5	0	92	230	
		Groundwater level monitoring well	Point	2.5	0	92	230	
		Fire hydrant	Point	2.5	0	92	230	
		Water valve	Point	2.5	0	92	230	
		Water supply pipeline	Line	$800\frac{1.5}{2.5}$ 1.0	0	92	230	800: Diameter, 1.5 ground elevation, 2.5 object depth, 1.0 line weight (mm)
		Water supply pipeline (half-scale)	Line	$800\frac{1.5}{2.5}$ 0.2	0	92	230	800: Diameter 800, 1.5 ground elevation, 2.5 object depth, 0.2 line weight (mm)
		Underground clean water storage tank	Fill	$\frac{1.5}{0.3}$	0	92	230	1.5 ground elevation, 0.3 object depth
2.2	Drainage	Wastewater drainage culvert	Point	2.5	115	38	0	
		Rainwater drainage culvert, combined sewer	Point	2.5	115	38	0	
		Pumping station	Point	2.5	115	38	0	
		Exposed connection point and waste collection	Point	2.5	115	38	0	
		Wastewater drainage pipeline	Line	$800\frac{1.5}{3.5}$ 1.0	212	94	0	800: Diameter, 1.5 ground elevation, 3.5 object depth, 1.0 line weight (mm)

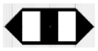
Continued Table 3

No.	Object		Object type	Symbol 1:200. 1:500. 1:1000. 1:2000	Color R	Color G	Color B	Explanation
		Wastewater drainage pipeline (half scale)	Line	$800\frac{1.5}{3.5}$ 0.2	212	94	0	800: Diameter, 1.5 ground elevation, 3.5 object depth, 0.2 line weight (mm)
		Underground wastewater settling tank	Fill	 2.5	199	127	117	
2.3	Electricity	Underground power line	Line	$35\frac{1.5}{0.5}$ 0.6	230	0	169	35: Voltage (KV), 1.5 ground elevation, 0.5 object depth, 0.6 line weight (mm)
		Underground power line (half-scale)	Line	$35\frac{1.5}{0.5}$ 0.1	230	0	169	35: Voltage (KV), 1.5 ground elevation, 0.5 object depth, 0.1 line weight (mm)
		Power cable conduit	Line	$6-35\frac{1.5}{0.5}$ 1.0	230	0	169	6: Number of cable lines, 35: Voltage (KV), 1.5 ground elevation, 0.5 object depth, 1.0 line weight (mm)
		Power cable marker	Point	 2.5	230	0	169	
		Lighting pole	Point	 2.5	230	0	169	
		Transformer pole	Point	 2.5	230	0	169	
		Transformer station	Point	 2.5	230	0	169	
2.4	Telecommuni-cations	Telecommunication cable	Line	$100\frac{1.5}{0.5}$ 0.4	112	168	0	100: Diameter, 1.5 ground elevation, 0.5 object depth, 0.4 line weight (mm)
		Telecommunication cable (half scale)	Line	$100\frac{1.5}{0.5}$ 0.1	112	168	0	100: Diameter, 1.5 ground elevation, 0.5 object depth, 0.1 line weight (mm)
		Telecommunication cable conduit	Line	$6-800\frac{1.5}{0.5}$ 1.0	168	168	0	6: Number of cable lines, 800: Diameter, 1.5 ground elevation, 0.5 object depth, 1.0 line weight (mm)
		Post office	Point	 2.5	168	168	0	
		Telephone booth	Point	 2.5	115	115	0	
		Exposed connection point of telecommunication cable	Point	 2.5	168	168	0	
		Telecommunication cable marker	Point	 2.5	112	168	0	
2.5	Energy	Energy pipeline	Line	$\text{KT-500}\frac{1.5}{1.5}$ 0.5	255	0	0	Function (KT: Coal gas; HL: Liquefied gas; TN: Natural gas…), 500: Diameter, 1.5 ground elevation, 1.5 object depth, 0.5 line weight (mm)

Continued Table 3

No.	Object		Object type	Symbol 1:200. 1:500. 1:1000. 1:2000	Color			Explanation
					R	G	B	
		Energy pipeline	Line	KT-500 $\frac{1.5}{1.5}$ 0.1				
		Energy pipeline marker	Point	 2.5	255	0	0	
		Exposed connection point of energy objects	Point	 2.5	255	0	0	
		Control valve	Point	 2.5	255	190	190	
		Gas storage tank	Fill	 $\frac{1.5}{1.2}$	255	127	127	1.5 ground elevation, 1.2 object depth
2.6	Chemicals	Control valve	Point	 2.5	255	255	0	
		Pressure reduction station	Point	2.5	255	211	127	
		Exposed connection point of energy objects	Point	 2.5	255	170	0	
		Chemical pipeline	Line	DM-600 $\frac{1.2}{1.5}$ 0.6	255	255	0	DM: Oil (pipeline function), 600: Diameter, 1.2 ground elevation, 1.5 object depth, 0.6 line weight (mm)
		Chemical pipeline (half scale)	Line	DM-600 $\frac{1.2}{1.5}$ 0.2	255	255	0	DM: Oil (pipeline function), 600: Diameter, 1.2 ground elevation, 1.5 object depth, 0.2 line weight (mm)
		Chemical storage tank	Fill	 $\frac{1.2}{1.5}$	255	255	190	1.2 ground elevation, 1.5 object depth
2.7	Tunnels, trenches, culverts, technical chambers	Technical culvert and chamber	Point	 2.5	0	0	0	
		Technical tunnel/ underground passage	Line	800 $\frac{1.2}{2.5}$ 1.5	0	0	0	800: Width of tunnel/ underground passage, 1.2 ground elevation, 2.5 object depth, 1.5 line weight (mm)
		Technical tunnel/ underground passage (half-scale)	Line	800 $\frac{1.2}{2.5}$ 0.2	0	0	0	800: Width of tunnel/ underground passage, 1.2 ground elevation, 2.5 object depth, 0.2 line weight (mm)
		Underground trench	Line	800 $\frac{1.2}{2.5}$ 1.5	0	38	115	800: Width of trench, 1.2 ground elevation, 2.5 object depth, 1.5 line weight (mm)
		Underground trench (half-scale)	Line	800 $\frac{1.2}{2.5}$ 0.2				800: Width of trench, 1.2 ground elevation, 2.5 object depth, 0.2 line weight (mm)

End of Table 3

No.	Object		Object type	Symbol 1:200. 1:500. 1:1000. 1:2000	Color			Explanation
					R	G	B	
2.8	Natural objects	Water pockets, water lenses	Point	 3.0	0	0	0	
		Cracks and voids	Point	 2.5	0	0	0	
		Geological fault	Line	0.4	0	0	0	

3.6. Proposed solutions to improve the effectiveness of underground surveys using GPR

To improve survey effectiveness, in addition to applying the above technical regulations, the standard also proposes some combined solutions such as:

- Using independent geophysical methods such as electromagnetic, seismic, and electrical resistivity… to cross-check results and supplement information that GPR is difficult to detect, such as depth to bedrock, thick soil layers…
- Integrating GPR data with GIS data, base topographic maps, and accurate positioning information by GNSS to improve the accuracy of the position and shape of objects.
- Conducting GPR measurements at different frequencies, integrating results from multiple antennas with different parameters to increase the ability to interpret complex objects.
- Building 3D models from 2D GPR data to better visualize objects' spatial shape and relationship. Building 3D databases of underground objects for easy management and exploitation later.

3.7. Regulations on equipment inspection and product quality assessment

Regarding GPR equipment inspection: The standard stipulates that GPR equipment inspection includes two main parts: static and dynamic state inspection. The inspection aims to evaluate the operating condition of machinery and equipment before putting them into official use for field scanning. Specific inspection steps are performed in sequence, including observing the wave field on the recording tape in static mode and comparing results between test measurements in dynamic mode. Machinery is only qualified when it gives stable and consistent results through inspections.

Regarding product quality assessment, the standard stipulates main criteria, including:

- Form and content: Products must have 2D object distribution maps on a 1:500 to 1:2,000 scale, an explanatory results report, and complete raw data as prescribed.
- Accuracy: Check the horizontal positioning error and depth of measurement points compared to control points to classify into one of 4 corresponding quality levels. Use at least one independent survey method to randomly verify ≥5% of detected objects.

3.8. Developing a process for surveying, measuring, and mapping shallow layer geography using GPR

Based on the synthesis of the above research results, the standard proposes an implementation process (Figure 2) consisting of 9 main steps as follows:

1. Survey the mapping area: Determine the construction area, survey exposed connection points, terrain, and soil environment, prepare reports, and propose technical solutions.
2. Preparation work: Collect documents, prepare machines and measuring equipment, and implement labor safety plans.
3. Edit base map: Divide sheets and edit content layers, including control points, topography, hydrology, transportation, population, and administrative boundaries…
4. Design scanning plan: Design grid and scanning routes, check sections, and labor safety plans.
5. Conduct field scanning: Create ground surface, arrange grid, install equipment, set scanning parameters, deploy safety plans, and conduct scanning according to design.
6. Process data: Check data, process GNSS/total station data, analyze and interpret images and position object coordinates.
7. Edit maps and prepare reports: Edit object layers, assign attributes, review and compare documents, and present maps and summary reports.
8. Quality control: Check geodetic work, scanning according to design, depth, and object attributes.
9. Package and deliver products according to phases, including reports, maps, raw data, measurement books, and inspection results.

This process ensures logic and systematization while being suitable to the sequence and specifics of GPR survey work in Vietnam today. Adhering to this process will improve the quality and efficiency of shallow geological investigation activities using GPR.

3.9. Discussion

3.9.1. Applicability of the standard in Vietnam

The proposed technical standard in this study has high application potential in Vietnam for the following reasons:

Firstly, the standard is built based on selective inheritance from reputable international standards such as PAS 128:2014 of the UK, ASCE 38-02 and ASCE 38-22 of the USA, and AS 5488 of Australia while adjusting for Vietnam's conditions to ensure updating and compliance with international trends while taking into account Vietnam's specifics.

Secondly, the process and technical requirements are designed to suit Vietnam's current technology level and human resources. For example, the division of 4 quality levels (QLB1-QLB4) allows flexibility in application, depending on the specific requirements of each project and the capability of the implementing unit.

Thirdly, the standard has considered the diversity of underground objects in Vietnam, including technical infrastructure works and natural objects. This helps the standard to be comprehensive and widely applicable in many fields.

3.9.2. Comparison of advantages and disadvantages with international standards

The main advantage of the proposed standard compared to international standards is its comprehensiveness and suitability for Vietnam's conditions. Specifically:

- The standard covers surveys to mapping, creating a complete and consistent process.
- Particular attention is paid to specific regulations on map representation that are suitable for urban management practices in Vietnam.
- Integrates environmental factors characteristic of Vietnam into calculations and technical regulations.

However, this standard also has some limitations compared to advanced international standards:

- The integration of GPR data with other advanced survey technologies like US or UK standards is not yet mentioned in depth.
- No specific guidelines on building and managing 3D databases for underground objects, a strongly developing trend worldwide.

3.9.3. Challenges when implementing the standard

Implementing this standard in Vietnam may face some challenges:

- Human resource training: It takes time to train technical staff to master new processes and technical requirements. In particular, interpreting and processing GPR data requires in-depth skills and experience.
- Equipment investment: Some units may need to upgrade or invest in new GPR equipment to meet technical requirements. This can create financial barriers, especially for small units.
- Changing work habits: It takes time for units to adapt to new processes, especially in data processing and map editing.
- Data synchronization: Integrating GPR data with existing geographic information systems can be difficult due to differences in data formats and structures.

3.9.4. Proposed solutions to overcome limitations

To overcome the above limitations and challenges, the study proposes some solutions:

- Organize training courses on new standards for relevant units. Emphasis should be placed on practical training, especially GPR data processing and interpretation skills.
- Develop a roadmap for applying standards, allowing a transition period for units to prepare in terms of human resources, equipment, and work processes.
- Adapt and optimize existing GPR data processing software for Vietnam's specific conditions, leveraging well-established tools while tailoring them to local requirements, enhancing efficiency and reducing implementation time.
- Continue research and update standards to supplement content on integrating new technologies and build and manage 3D databases for underground objects.
- Promote international cooperation to learn experiences and update the latest technologies in this field.

4. Conclusions

Using the GPR method, this study has developed a draft basic standard specifying the technical process of surveying, measuring, and mapping underground objects in the shallow layer. The main results achieved include:

- Identifying a list of 8 groups of 31 main object types that need to be investigated by GPR within 6 m from the ground surface.
- Analyzing and stipulating the main factors affecting GPR efficiency, such as antenna frequency, environmental characteristics, material, and object depth, proposing equations to determine optimal antenna frequency.
- Stipulating basic contents and technical requirements on geodetic work, preliminary field survey, and GPR measurement network design.
- Dividing four quality levels on horizontal positioning accuracy and depth corresponding to GPR application capability.
- Stipulating basic principles on content representation presentation of 2D maps of underground objects.
- Proposing some solutions combined with other methods to improve GPR survey efficiency.
- Regulations on equipment inspection and main criteria to evaluate survey product quality.

- GPR's survey, measurement, and mapping process includes nine main steps.

Furthermore, this study recognizes the importance of GPR system configurations in surveying applications. While the standard provides a comprehensive framework for GPR usage, it also acknowledges that specific project requirements may necessitate different approaches. For instance, the choice between single-channel radars, multi-channel paired radars, and multi-channel radars with synthetic aperture and the selection of signal strength (stroboscopic, low-pulse, or high-power) can significantly impact survey outcomes. These considerations, while beyond the scope of the current standard, are crucial for achieving optimal results across various environmental conditions.

This standard, when issued, will be the first document to standardize the application of GPR in surveying, measuring, and mapping underground objects in the shallow layer in Vietnam, contributing to promoting the widespread application of this advanced technology in practice. It will serve as an important legal basis for functional agencies to manage and control the quality of shallow geophysical survey activities. Additionally, it will provide a useful guide for specialized consulting and construction units in designing and implementing projects for investigation and exploration using the GPR method.

As GPR technology evolves, future research and standards development should incorporate more detailed guidance on system configurations and signal strength selection. This will ensure that the standard remains comprehensive and up-to-date, providing thorough guidance for GPR applications in Vietnam's diverse geological and urban environments.

References

AM/FM Technical Sub-Committee, & National Mapping and Spatial Data Committee. (2006). *Standard guideline for underground utility mapping*. https://www.geomatic.com.my/public/files/b9d77d8d1c1f51ca2d0c13004ffd5165e58f226fbf8d64b-32612cc54af875a7a.pdf

American Society for Testing and Materials. (1999). *Standard guide for using the surface ground penetrating radar method for subsurface investigation* (D6432-99, p. 17). ASTM.

American Society of Civil Engineers. (2002). *Standard guideline for the collection and depiction of existing subsurface utility data* (ASCE 38-02, p. 33). ASCE.

American Society of Civil Engineers. (2022). *Standard guideline for investigating and documenting existing utilities* (ASCE 38-22, p. 86). ASCE.

Beijing Surveying Design Institute. (2017). *Technical specification for urban underground pipeline detection and survey*. Housing and Urban-Rural Development.

Bennett, B. (2023). *Subsurface utilities Part 2*: *The capture & recording*. https://www.bennettandbennett.com.au/subsurface-utilities-part-2-the-capture-recording/

Bộ Xây dựng. (2016a). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình cấp điện* [National technical regulation on technical infrastructure works – Power supply projects] (QCVN 07-5:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Bộ Xây dựng. (2016b). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình cấp nước* [National technical regulation on technical infrastructure works – Water supply projects] (QCVN 07-1:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Bộ Xây dựng. (2016c). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình cấp xăng, dầu, khí đốt* [National technical regulation on technical infrastructure works – Gasoline, oil and gas supply projects] (QCVN 07-6:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Bộ Xây dựng. (2016d). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình chiếu sáng* [National technical regulation on technical infrastructure works – Lighting projects] (QCVN 07-7:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Bộ Xây dựng. (2016e). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình giao thông* [National technical regulation on technical infrastructure works – Transportation projects] (QCVN 07-4:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Bộ Xây dựng. (2016f). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình hào và tuynen kỹ thuật* [National technical regulation on technical infrastructure works – Technical trenches and tunnels] (QCVN 07-3:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Bộ Xây dựng. (2016g). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình thoát nước* [National technical regulation on technical infrastructure works – Drainage projects] (QCVN 07-2:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Bộ Xây dựng. (2016h). *Quy chuẩn kỹ thuật quốc gia – Các công trình hạ tầng kỹ thuật – Công trình viễn thông* [National technical regulation on technical infrastructure works – Telecommunications projects] (QCVN 07-8:2016/BXD). Hội Môi trường Xây dựng Việt Nam, chủ biên, Bộ Xây dựng, Hà Nội.

Butler, L. (2019). *What lies beneath*: *Updating AS 5488*. https://www.utilitymagazine.com.au/what-lies-beneath-updating-as-5488/

Engineering Education Australia. (2023). *Upgraded subsurface utility standard comes into affect*. https://eea.org.au/insights-articles/upgraded-subsurface-utility-standard-comes-affect

Institution of Civil Engineers. (2014). *Specification for underground utility detection*, *verification and location*. The British Standards Institution.

Ji, G., Gao, X., Zhang, H., & Gulliver, T. A. (2009). Subsurface object detection using UWB Ground Penetrating Radar. In *2009 IEEE Pacific Rim Conference on Communications*, *Computers and Signal Processing* (pp. 740–743). Victoria, BC, Canada. https://doi.org/10.1109/PACRIM.2009.5291279

Nguyễn, V. C., Dương, V. T., & Lường, T. H. (2021). Đề xuất quy trình công nghệ xác định đối tượng xả thải ngầm bằng thiết bị georadar (GPR) RIS MF Hi-Mod #4 [Proposal on technological process for identifying underground discharge objects by using georadar (GPR) RIS MF Hi-Mod #4 equipment]. *Tạp chí Khoa học Đo đạc và Bản đồ*, (47), 42–47. https://doi.org/10.54491/jgac.2021.47.238

Nguyễn, V. G., Nguyễn, H. V., Jarzyna, J., Zietek, J., & Nguyễn, V. D. (2023). Áp dụng phương pháp Georadar để nghiên cứu trên các mẫu vật và mô hình ở Việt Nam [Application of the Georadar method for research on samples and models in Vietnam]. *Tập san Khoa học và kỹ thuật trường Đại học Bình Dương*, *6*. https://doi.org/10.56097/binhduonguniversityjournalofscienceandtechnology.v6i1.92

Stokes, A., Fourcaud, T., Hruska, J., Cermák, J., Nadyezdhina, N., Nadyezhdin, V., & Praus, L. (2002). An evaluation of different methods to investigate root system architecture of urban trees *in situ*: I. Ground-Penetrating Radar. *Journal of Arboriculture*, *28*, 2–10. https://doi.org/10.48044/jauf.2002.001

Strange, A. D., & Yelf, R. J. (2012). What is the true time range of a GPR system? In *14th International Conference on Ground Penetrating Radar* (*GPR*) (pp. 436–440). Shanghai, China. https://doi.org/10.1109/ICGPR.2012.6254905

Tổng Cục Địa chất và Khoáng sản. (2012). *Tiêu chuẩn quốc gia TCVN 9426:2012 về Điều tra*, *đánh giá và thăm dò khoáng sản – Phương pháp Georada* [National standard TCVN 9426:2012 on Mineral investigation, assessment and exploration – Georadar method]. Việt Nam, Bộ Khoa học và Công nghệ.

Trần, V. T. (2011). Ứng dụng Radar xuyên đất (GPR) để dò tìm và đo vẽ bản đồ công trình ngầm đô thị [Application of Ground Penetrating Radar (GPR) for detecting and mapping urban underground structures]. *Tạp chí Khoa học Đo đạc và Bản đồ*, (8), 12–15. https://doi.org/10.54491/jgac.2011.8.449

Trần, V. T. (2012). Nghiên cứu một số giải pháp nâng cao hiệu quả dò tìm công trình ngầm bằng thiết bị radar xuyên đất ramax/x3m [Research on solutions to improve the efficiency of underground structure detection using ramac/x3m ground penetrating radar equipment]. *Tạp chí Khoa học Đo đạc và Bản đồ*, (13), 8–12. https://doi.org/10.54491/jgac.2012.13.494

Utsi, V. (2014). Detection of Fibre Optic cables using GPR. In *Proceedings of the 15th International Conference on Ground Penetrating Radar* (pp. 465–468). Brussels, Belgium. https://doi.org/10.1109/ICGPR.2014.6970467