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[Mohamed Said Elkordy](#) *

Posted Date: 9 March 2026

doi: 10.20944/preprints202603.0606.v1

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Article

Managing Subsurface Utility Risk in Large-Scale Water Infrastructure Projects: A Comparative Assessment of GPR, As-Built Records, and Trial Pits

Mohamed Said Elkordy

Department of Civil Engineering, Alexandria University, Egypt, 21523, Alexandria, Egypt;
mohamedsaidelkordy or @stuabroad.moe.edu.eg or saidsadalla@gmail.com

Abstract

Underground utilities represent a critical risk factor in large-scale water infrastructure projects, particularly in dense urban environments such as Riyadh, KSA. This paper presents a comparative technical assessment of three primary methods used for subsurface utility detection and verification in a TSE (Treated Sewage Effluent) network construction project: Ground Penetrating Radar (GPR), existing as-built drawings, and site trial pit investigations. The study evaluates the accuracy, reliability, and limitations of each method, with a specific focus on deep utilities exceeding 6 meters in depth. A real project case is analyzed where GPR failed to detect an existing utility pipe at approximately 13 meters depth, resulting in a microtunneling collision. The incident is used to explore root causes, including high soil cover levels, surface reinstatement conditions, and signal attenuation mechanisms. The paper further discusses the project-level implications of relying solely on GPR and historical records without adequate trial pit verification, including time delays, cost overruns, and risk exposure in large-scale KSA infrastructure programs. The findings highlight that while GPR and as-built records are valuable planning tools, they are insufficient as standalone methods for deep utility risk management. The paper concludes with a set of practical lessons learned and recommendations for site engineers and project managers, emphasizing the need for a hybrid verification strategy that systematically integrates GPR, document review, and targeted trial pits for high-risk sections.

Keywords: ground penetrating radar; trial pits; as-built drawings; deep utilities; microtunneling; risk management; TSE network; riyadh; KSA; infrastructure projects

1. Introduction

Large-scale water infrastructure projects in the Kingdom of Saudi Arabia (KSA), particularly in rapidly developing cities such as Riyadh, face increasing complexity due to dense underground utility networks. Treated Sewage Effluent (TSE) networks, potable water lines, stormwater systems, electrical ducts, and telecommunication conduits often coexist within constrained corridors. This creates a high risk of clashes, damage, and delays during construction.

In the context of a TSE Network – Group Construction project in Riyadh, subsurface utility risk emerged as a critical factor affecting microtunneling works and open-cut excavations. Project teams typically rely on three main sources of information for underground utility detection:

- Ground Penetrating Radar (GPR) surveys
- Existing as-built drawings and records
- Site trial pit investigations

While GPR is often perceived as a modern and “high-certainty” detection tool, its performance is highly dependent on soil conditions, depth, moisture content, and surface reinstatement. As-built drawings may be outdated, incomplete, or inaccurate. Trial pits, although intrusive and time-consuming, remain the most direct and reliable verification method.

This paper aims to:

- Compare the **certainty and reliability** of GPR, as-built drawings, and trial pits in the context of water infrastructure projects in Riyadh.
- Analyze **deep utility risks**, particularly for utilities deeper than 6 m.
- Present a **case study** where GPR failed to detect a 13 m deep utility, leading to a microtunneling collision.
- Extract **root causes and lessons learned** relevant to site engineers and project managers.
- Propose a **practical framework** for subsurface utility risk management in large-scale KSA projects.

2. Background and Literature Context

2.1. Subsurface Utilities as a Project Risk

Underground utilities are a major source of uncertainty in infrastructure projects. Undetected or mislocated utilities can lead to:

- Damage to existing services
- Safety incidents
- Microtunneling machine damage or blockage
- Re-design and re-routing
- Claims, disputes, and delays

In large-scale programs, such as national water and TSE networks in KSA, these risks scale up significantly due to the length of corridors and the density of existing services.

2.2. Common Methods for Underground Utility Detection

Three main methods are widely used in practice:

- As-built drawings:** Historical records prepared after construction.
- GPR surveys:** Non-destructive geophysical method using electromagnetic waves.
- Trial pits:** Localized excavations to visually confirm the presence, depth, and alignment of utilities.

Each method has strengths and limitations, which must be understood and managed rather than assumed to be fully reliable.

3. Methods Compared: GPR, As-Built Drawings, and Trial Pits

3.1. As-Built Drawings

Strengths:

- Provide initial indication of utility routes and depths.
- Useful for early planning, alignment studies, and clash analysis.
- Low cost to use (already available).

Limitations:

- May be outdated due to later modifications.
- Often lack accurate depth information.
- Horizontal alignment may deviate due to construction tolerances.
- Quality depends on original contractor and supervision.

In Riyadh, many legacy networks were constructed before strict digital standards, leading to variable reliability.

3.2. Ground Penetrating Radar (GPR)

Principle:

GPR transmits electromagnetic waves into the ground and records reflections from interfaces between materials with different dielectric properties (e.g., soil vs pipe).

Strengths:

- Non-destructive and relatively fast.
- Can detect non-metallic utilities (e.g., PVC, concrete) under suitable conditions.
- Provides continuous profiles along survey lines.
- Useful for mapping shallow to moderate depth utilities.

Limitations:

- Performance degrades significantly with depth.
- High-conductivity or high-moisture soils attenuate signals.
- Thick fill layers and multiple reinstatements scatter and absorb energy.
- Interpretation requires expertise and is not always straightforward.
- Deep utilities (>6 m) are often beyond practical detection limits in real site conditions.

3.3. Trial Pit Investigations

Strengths:

- Direct visual confirmation of utility presence, depth, size, and material.
- Highest certainty among the three methods.
- Can verify or correct as-built and GPR findings.

Limitations:

- Intrusive and time-consuming.
- Requires traffic management and safety measures.
- Not feasible to perform continuously along the entire alignment.
- Costly if overused without risk-based targeting.

4. Comparative Assessment Framework

To compare the three methods in the context of the Riyadh TSE project, we consider:

- Accuracy and reliability
- Depth performance (especially >6 m)
- Risk of false negatives (missed utilities)
- Practicality in large-scale projects
- Cost and time implications

4.1. Accuracy and Reliability

- As-built drawings:** Medium reliability; dependent on original construction quality and updates.
- GPR:** Medium to high reliability for shallow utilities (e.g., 0–3 m), decreasing with depth and soil complexity.
- Trial pits:** High reliability at specific locations.

4.2. Deep Utilities (>6 m)

- As-built:** May indicate presence but depth often uncertain.
- GPR:** Performance significantly reduced; deep utilities may not be detected, especially in layered or high-moisture soils.
- Trial pits:** Still reliable but more complex and costly to execute at such depths.

4.3. Risk of Missed Utilities (False Negatives)

- Highest risk:** GPR alone in deep or complex soil conditions.
- Moderate risk:** As-built drawings without field verification.
- Lowest risk:** Trial pits at critical locations.

5. Case Study: GPR Failure at 13 M Depth and Microtunneling Collision

5.1. Project Context

The case occurred in a **TSE Network – Group Construction project in Riyadh, KSA**, involving microtunneling works for deep pipelines. The alignment passed through an area with known existing utilities, but their exact depth and position were uncertain.

5.2. Pre-Construction Investigations

The following steps were performed:

- Collection of **as-built drawings** from previous projects.
- Execution of **GPR surveys** along the proposed microtunneling alignment.
- Limited **trial pits** performed at selected chainages, mainly for shallow crossings.

The GPR results did not indicate any significant deep utility at the critical chainage where the incident later occurred.

5.3. Incident Description

During microtunneling at approximately **13 m depth**, the microtunneling machine collided with an existing utility pipe that had not been detected by GPR and was either missing or inaccurately represented in the as-built records.

Consequences included:

- Stoppage of tunneling operations.
- Damage to the existing utility.
- Need for emergency repair and redesign.
- Time delays and additional costs.

5.4. Root Cause Analysis

Key contributing factors included:

Depth limitation of GPR:

The utility was at ~13 m depth, beyond the practical detection range under the given soil conditions.

Signal attenuation increased with depth and soil moisture.

High soil levels and multiple reinstatements:

The area had undergone several construction cycles, with layers of backfill, compaction, and reinstatement.

These layers caused scattering and attenuation of GPR signals, reducing clarity at depth.

Clear surface reinstatement (no visible signs):

The surface appeared uniform and fully reinstated, giving a false sense of “clean” subsurface conditions.

No visual cues existed to trigger suspicion of deep legacy utilities.

Over-reliance on GPR and as-built records:

Trial pits were not extended to deeper levels at high-risk chainages.

The project team assumed that “no GPR signal = no utility,” which is a dangerous assumption for deep utilities.

6. Technical Discussion: GPR Limitations in Deep Utility Detection

6.1. Signal Attenuation Mechanisms

GPR performance is governed by:

- Soil conductivity and moisture:** Higher conductivity and moisture increase attenuation.
- Depth:** Signal strength decays exponentially with depth.

Frequency used: Higher frequencies give better resolution but lower penetration; lower frequencies penetrate deeper but with less detail.

In Riyadh's urban areas, backfilled corridors often contain:

Mixed materials (sand, gravel, concrete fragments).

Variable moisture content due to leaks or irrigation.

Multiple utility layers.

These conditions significantly reduce the effective penetration depth of GPR.

6.2. Practical Depth Limits

Although theoretical GPR penetration can reach several meters in ideal dry sand, in real project conditions:

Reliable detection for utilities is often limited to **3–5 m**.

Beyond **6 m**, detection becomes uncertain and highly site-dependent.

At **13 m**, as in the case study, GPR non-detection is not surprising.

7. Project Impact: Time and Cost Implications

While exact figures vary by project, the general impacts of failing to detect deep utilities include:

Time delays:

Stoppage of microtunneling works.

Time for investigation, repair, redesign, and approvals.

Potential delays of several weeks to months on critical path activities.

Cost impacts:

Repair of damaged utilities.

Additional microtunneling or re-routing.

Standby costs for equipment and crews.

Possible claims from affected stakeholders.

In large-scale KSA infrastructure programs, such as city-wide TSE networks, even a small percentage of undetected deep utilities can translate into significant cumulative delays and cost overruns.

8. Lessons Learned for Site Engineers and Project Managers

8.1. GPR Is a Support Tool, Not a Guarantee

GPR should be treated as **one input among several**, not as a definitive map of all utilities.

"No signal" does **not** mean "no utility," especially at depths >6 m.

8.2. Deep Utilities Require Special Treatment

Any section where utilities may exist deeper than 6 m should be classified as **high-risk**.

For such sections, **trial pits or shaft investigations** should be considered mandatory before microtunneling.

8.3. Risk-Based Trial Pit Strategy

Instead of trial pits everywhere (which is impractical), adopt a **risk-based approach**:

Use as-built + GPR to identify suspicious or congested zones.

Perform **targeted deep trial pits** at critical chainages and crossings.

8.4. Do Not Trust "Clean Surface" as Evidence

Clear reinstatement and uniform asphalt do not mean the subsurface is empty.

Legacy utilities may be buried deep with no surface indication.

8.5. Documentation and Feedback Loop

Every incident (e.g., collision, unexpected utility) should be documented.

As-built records must be updated.

Lessons learned should be fed back into future alignment planning and risk assessments.

9. Proposed Practical Framework for Subsurface Utility Risk Management

A simple, implementable framework for projects similar to the Riyadh TSE network:

Desk study:

Collect all available as-built drawings and previous project records.

Identify corridors with high utility density.

Non-intrusive surveys (GPR and others):

Perform GPR along the proposed alignment.

Map anomalies and potential utility zones.

Risk classification:

Classify segments as low, medium, or high risk based on:

Depth of proposed works

Presence of existing utilities

Uncertainty in records

Criticality of the crossing

Targeted trial pits:

For **high-risk segments**, perform trial pits or shafts to confirm utility presence and depth.

For **medium-risk segments**, use selective trial pits.

For **low-risk segments**, rely on GPR + as-built, with contingency plans.

Design and method adjustment:

Adjust microtunneling alignment, depth, or method based on verified data.

Continuous update:

Update as-built records with verified information.

Capture lessons learned for future projects.

10. Conclusions

This paper has examined the relative certainty and limitations of GPR, as-built drawings, and trial pit investigations for underground utility detection in the context of a TSE network project in Riyadh, KSA. The case study of a 13 m deep undetected utility, which led to a microtunneling collision, demonstrates that:

GPR alone is **not sufficient** for deep utility risk management.

As-built drawings, while useful, cannot be fully trusted without field verification.

Trial pits, although more costly and intrusive, remain the **most reliable method** for confirming utilities at critical locations.

For large-scale infrastructure projects in KSA, a **hybrid, risk-based approach** is essential. Combining as-built records, GPR surveys, and targeted trial pits provides a more robust basis for decision-making, reduces the likelihood of costly incidents, and supports safer and more predictable project delivery.

The lessons learned presented in this paper are intended to support site engineers, project managers, and decision-makers in designing more resilient subsurface investigation strategies, particularly for deep utilities and microtunneling works.

11. Lessons Learned Summary for Site Engineers

For direct use in your report as a boxed section:

Never rely on a single method (GPR or as-built alone) for deep utilities.

Classify deep sections (>6 m) as high-risk and plan additional verification.

Treat “no GPR signal” as “uncertain,” not “safe.”

Use trial pits strategically at critical chainages and crossings.

Document every unexpected utility and update records immediately.

Include subsurface utility risk explicitly in the project risk register.

Communicate limitations of GPR clearly to stakeholders and management.

Acknowledgments: The author would like to express sincere appreciation to the project team members and site engineers involved in the TSE Network – Group Construction project in Riyadh, KSA, for their valuable insights and practical observations that contributed to the development of this study. Their field experience and technical input were essential in shaping the case analysis and lessons learned presented in this article.

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