Research on the applicability of high-precision underground exploration technology to public roads in Bangkok: Part 1 – Trend analysis of detected cavities

Mitsumasa Yamashina[1,*] Warat Kongkitkul[2] Jun Shinohara[3] Naoki Kinoshita[4] and Chana Phutthananon[5]

[1,3] Center for Disaster Management Informatics Research, Ehime University, Matsuyama, JAPAN

[2,5] Department of Civil Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangkok, THAILAND

[4] Department of Civil and Environmental Engineering, Ehime University, Matsuyama, JAPAN

**Corresponding author; E-mail address: mygotoservice.co@gmail.com*

Abstract

This study demonstrates the effectiveness of Ground Penetrating Radar Mobile Mapping System 3D (GMS3) technology in detecting subsurface cavities across various public road classifications in Thailand. A total survey length of 338 km identified 313 potential cavities, with comparable detection rates of 0.92, 0.94, and 0.93 cavities per lane (km) for urban main roads, urban sub-roads (Soi), and suburban main roads, respectively. Notably, the first lane of urban main roads showed a higher detection rate (1.21), over twice that of internal lanes (0.57), while suburban main roads exhibited a fivefold difference (2.12 vs. 0.04). Analysis of Bangkok's three generational zones revealed the lowest detection rate in Gen.3 (0.50), closely aligned with Japan's main road rate (0.44). Variations are attributed to infrastructural density and historical pavement quality. The GMS3 system effectively visualizes subsurface features up to 1.5 m deep, supporting its application in proactive and data-driven road asset management. These findings advocate for the use of cavity heat maps to inform infrastructure maintenance strategies.

Keywords: Ground penetrating radar, Mobile mapping system, Cavity detection, GMS3

1. Introduction

Cavities in major roads across Thailand present significant social and infrastructural challenges, with risk mitigation methods still under development. For example, in September 2022, a major cavity formed on Chaeng Watthana Road following several days of heavy rainfall, resulting in a collapse measuring approximately 2 meters wide, 5 meters long, and 2 meters deep, which caused severe traffic congestion. The affected area included a manhole used for underground electrical line installation. Similarly, in April 2024, another sinkhole emerged near Wat Bo Temple on Chaeng Watthana Road, likely associated with underground cable installation work, leading to the closure of two traffic lanes. In response, the Governor of Bangkok, in coordination with relevant authorities, announced in March 2025 plans to conduct further investigations in high-risk areas along Chaeng Watthana Road. Over the past two years, eight sinkholes have been reported on this road, with geological, anthropogenic, and environmental factors identified as potential contributors [1, 2].

The Ground Penetrating Radar Mobile Mapping System 3D (GMS3) was developed in 2015 by Canaan Geo Research Co., Ltd., with field validation conducted in collaboration with Ehime University in Japan since 2017. The system integrates ground penetrating radar (GPR) with an omnidirectional camera-based mobile mapping system (MMS), enabling the construction of a comprehensive subsurface information database for the accurate visualization of underground features. Widely presented in professional forums, GMS3 technology has been used to survey approximately 10,000 kilometers annually in Japan. This study aims to pilot the application of GMS3 technology on 338 kilometers of public roads in Thailand, evaluating its applicability and potential for cavity detection in the Bangkok metropolitan area.

2. Overview of GMS3 Technology

2.1 Ground penetrating radar (GPR)

The multi-channel array GPR facilitates three-dimensional

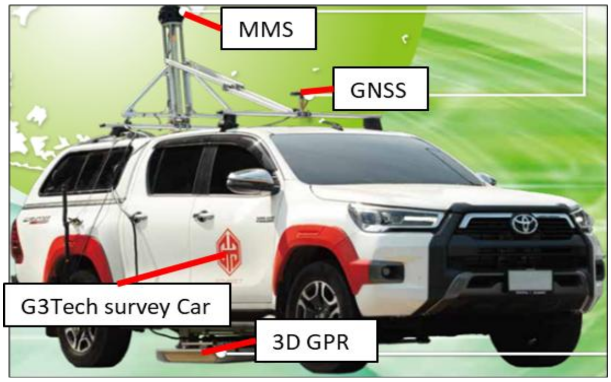

Fig. 1 Photo of the GMS3 brand (GM3Tech) in Thailand, featuring GPR under the vehicle and GNSS and MMS on the roof. The maximum

visualization of subsurface structures, enabling the identification of buried pipes and underground cavities through the detection of reflected electromagnetic waves emitted into the ground (Fig. 1). The performance of the radar is influenced by several factors, including the road surface's structure, soil type (e.g., clay or sand), moisture content, and groundwater level. In typical scenarios, the radar is capable of detecting features at depths of up to 1.5 m, while under optimal conditions, it can reach a maximum depth of 2.0 m. The GMS3 radar (Fig. 2) has a width of 1.8 m, so we propose allowing for two measurements per lane of the road to collect data in Thailand.

2.2 Mobile mapping system (MMS)

While it is feasible to identify cavities detected by radar within the subsurface profile, mapping their precise locations (coordinate positions) with an accuracy of less than 10 cm, required for civil engineering management, poses a technical challenge for subsequent in-situ drilling investigations (secondary surveys). The initial determination of these locations typically employs a Global Navigation Satellite System (GNSS); however, location spikes present a significant issue in many scenarios. To address this challenge, the implementation of Camera Vector (CV) processing through ground image MMS allows for the precise positioning of GPR data, effectively resolving this issue. This technology has been registered as a patented technique in Japan (2018) and classified as a New Technology Information System (NETIS), which is operated by the Japanese Ministry of Land, Infrastructure, Transport and Tourism. The GPR subsurface data acquired and analyzed via the aforementioned process, along with the MMS overground data, are synchronized using GNSS reference time as a linking key (Fig. 3). This synchronization

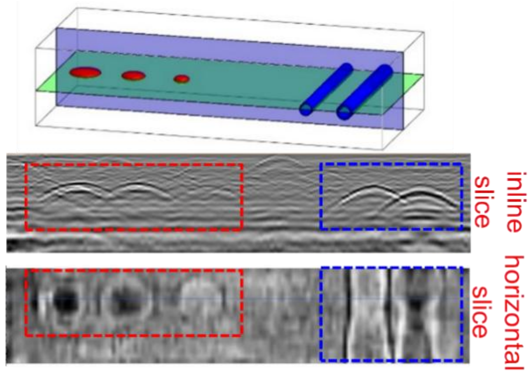

Fig. 2 GPR 3D radar images of underground survey of cavities (red dotted line) and buried pipes (blue dotted line).

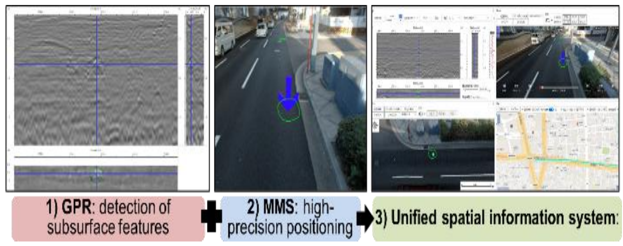

Fig. 3 Subsurface and surface data integration process in the GMS3 system.

enables the display and reporting of accurate locations for underground cavities and infrastructure through the utilization of a specialized viewer.

3. Analysis of Cavity Detection Trends, Taking into Account the Development History of Bangkok City

From 2024, a collaborative working group from Ehime University and King Mongkut's University of Technology Thonburi (KMUTT) conducted a study on cavities in public roads within the Bangkok metropolitan area. This study spanned a total survey lane distance of 338 km, during which 313 potential cavities were identified in the Thai public road. While the detected cavities do not guarantee the presence of voids at 100%, the actual existence of cavities at the candidate locations can be definitively verified through secondary investigations involving drilling. This technology has demonstrated a hit rate of 90.3% in public works projects in Japan.

As shown on the following map (Fig. 4), the target for co-research data collection will be Bangkok, the Urban area, and the suburban area. When examining the urbanization process of Bangkok, Urban area can be broadly divided into the old city area

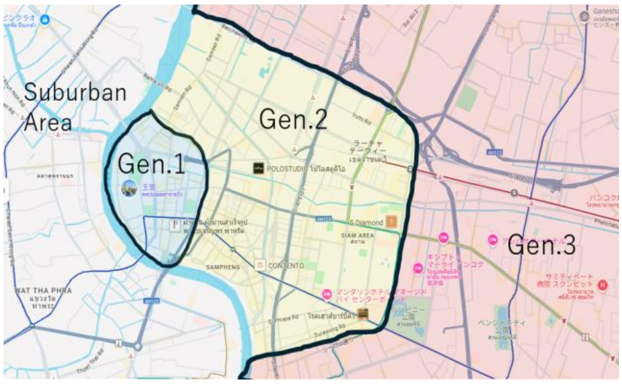

Fig. 4 Bangkok metropolitan area divided into four zones.

(Gen.1), which is over 200+ years old around the kingdom area, the second generation (Gen.2) that stretches from Ratchathewi Road to the Victory Memorial Building and Ratchadamri Road to the north and south, and the third generation (Gen.3) west of that [3].

The cavity detection rate (cavity numbers per km) was defined as the number of potential cavities identified per km of travel lane. Given the 1.8 m width of the GMS3 Rader, we conducted two measurements for each lane.

The detection rates for the three generational areas and suburban roads are presented in Table 1. The lowest detection rate was observed in Gen.3 (0.50), which is nearly identical to the discovery rate for main roads in Japan (0.44). In comparison to Gen.3, the detection rates for Gen.1 (0.89) and Suburban roads (0.93) were 1.76 and 1.83 times higher, respectively, while Gen.2 (1.63) exhibited the highest rate, at 3.22 times that of Gen.3.

These results suggest several factors: 1) The high density of buildings and infrastructure in the Gen.2 area and the active construction activity likely contributed to the elevated detection rate; 2) When the Gen.2 area was developed, the quality of infrastructure was not as high as it is today; 3) Until the year 2000, the active extraction of groundwater and associated subsidence of the ground [4, 5] may have also played a significant role.

Although this preliminary analysis serves as a showcase, we recommend that if continuous investigations are conducted in the urban center of Bangkok, further subdivisions of areas should be established based on the historical context of the roads and maintenance records. This would facilitate the creation of a cavity occurrence heat map, which could be utilized for road asset management.

Table 1 Cavity detected rate in Bangkok, Thailand.

Road attributes	Lane distance (km)	Number of possible cavities	Detected Rates
Gen1 area	52.7	47	0.89
Gen2 area	60.9	99	1.63
Gen3 area	97.1	49	0.50
Suburban rod	127.3	118	0.93

4. Case Study of Cavity Detection in Public Roads in Thailand

4.1 Differences in discovery rate depending on road attributes

We decided to classify the roads surveyed into three categories: 1) Trunk roads with two or more lanes in central Bangkok, 2) One-lane branch roads (Soi), and 3) Trunk main roads with two or more lanes in the suburbs of Bangkok, and compare the cavity detected rates between these three classifications.

The measured potential cavity data have been classified according to road attributes, as illustrated in Table 2. When comparing the cavity detection rates for urban main roads, urban sub-roads (Soi roads), and Suburban main roads, the respective detection rates were found to be 0.92, 0.94, and 0.93. These findings suggest that there are no statistically significant differences in detection rates based on road attributes for the roads examined. This detection rate is approximately twice that of the results we have observed along the national road in Japan. However, given the variations due to differences in road pavement structures and buried infrastructure, as well as the relatively more minor dataset available from Thailand, we do not consider this discrepancy to be problematic.

Table 3 presents the results of cavity potential investigations conducted in Japan, indicating that the discovery rate for Municipal and prefectural roads (2.0) is 4.54 times higher than that for National (arterial) roads (0.44). Research on cavity detection in Japan suggests that the elevated detection rate in municipal roads is primarily attributed to the high density of buried infrastructure, such as sewage systems and electrical lines [6]. In Thailand, however, urban sub-roads exhibit similarities in road structure and drainage systems to arterial roads, and the absence of underground electrical lines suggests that this factor does not contribute to variations in cavity detection rates between the two types of roads. As a result, it appears plausible that these structural and infrastructural similarities account for the lack of significant differences in detection rates. We will continue to broaden our dataset and enhance our analyses to investigate these observations further.

Table 2 Number of potential cavities detected by road attributes on public roads in Thailand.

Road attributes	Lane distance (km)	Number of possible cavities	Detected Rates
Urban main road	185.3	171	0.92
Urban sub-road (Soi roads)	25.4	24	0.94
Suburban main road	127.3	118	0.93

Table 3 Number of potential cavities discovered by road attributes on public roads in Japan [6].

Road attributes	Lane distance (km)	Number of possible cavities	Detected Rates
National road	6418	2848	0.44
Municipal and prefectural road	696	1395	2.00

Table 4 Classification of detected cavities based on pavement structure and road attributes in Bangkok.

Road attributes	Asphalt pavement	Concrete pavement
Urban main road	139 (81%)	32 (19%)
Urban sub-road (Soi roads)	10 (42%)	14 (58%)
Suburban main road	2 (7%)	27 (93%)
Total	151 (67%)	73 (33%)

Among the 313 identified locations by our survey in Thailand, a classification of the 224 cavities, for which the pavement structure was confirmed via radar images to be either asphalt or concrete, is presented in Table 4.

In Thailand, road pavements are mainly asphalt due to high traffic volumes, but concrete is used in some areas for its durability. Sub-roads typically use asphalt but may consider concrete for drainage and durability. In Japan, asphalt is more common, and the Japanese focus is on assessing cavities beneath it. Structurally, cavities under concrete tend to be larger due to its shear rigidity. Thai road collapses often exceed 2 m, and it is hypothesized that the jointed concrete structure leads to a larger critical cavity diam for collapses compared to asphalt. This aspect will be further deepened in Part 2. Among the 224 locations analyzed out of 313, 73 (33%) are concrete pavements, demonstrating that the cavity investigation capabilities of GMS3 can be effectively utilized even on concrete surfaces, especially in suburban main roads where concrete pavement is frequently employed. Moving forward, there is an urgent need to establish knowledge for risk assessment specific to concrete pavements in Thailand, which will be reported in Part 2 of this report.

Table 5 Classification of detected cavities by road lane in Bangkok.

Road attributes	Lane location	Lane distance (km)	Number of possible cavities	Detected Rates
Urban main road	Outer (1st) lane	101.8	123	1.21
Urban main road	Internal lane	83.5	48	0.57
Suburban main road	Outer (1st) lane	39.2	83	2.12
Suburban main road	Internal lane	88.1	35	0.40

Note: Urban sub-road (0.94) has only one lane

4.2 Consideration of the tendency of the cavity to occur in road lanes

The measured data were subsequently analyzed as cavity detection rates per road lane (Table 5). This analysis is informed by preliminary investigations indicating that a significant concentration of underground infrastructure is present in the first lane. Additionally, the road's structural characteristics include a gradient sloping outward, resulting in frequent water accumulation in the first lane. Consequently, the data were categorized based on two-lane attributes: the first and internal lanes.

As a result, in urban main roads, the cavity detection rate for the first lane (1.21) was found to be 2.10 times higher than that of the internal lanes (0.57). Similarly, in suburban main roads, the detection rate for the first lane (2.12) was 5.32 times higher than that of the internal lanes (0.40). These findings clearly indicate a higher risk of cavity formation in the first lane.

From a road asset management perspective, when conducting underground cavity surveys with constrained costs, it is suggested that focusing investigations on lanes with a high concentration of infrastructure, particularly those associated with sewage systems or electrical infrastructure, may enable more effective investment in research with limited resources.

5. Recommendations in Light of the March 2025 Myanmar Earthquake

The magnitude 7.7 earthquake that struck near Mandalay, Myanmar, on March 28, 2025, also significantly impacted high-rise buildings in Bangkok, located approximately 800–1000 km from the epicenter. This is attributed to Bangkok's construction on relatively weak alluvial soil along the Chao Phraya River, which amplifies long-period seismic waves from distant events [7]. Studies on the effects of earthquakes in Japan have identified a tendency for increased occurrences of road collapses and underground cavities following major seismic events [8]. These cavities frequently occur near subsurface drainage structures, such as sewers and other underground infrastructure. The potential causes include (1) damage to infrastructure junctions due to seismic motion; (2) pre-existing cavities rapidly collapsing and expanding as a result of the earthquake; and (3) alterations in groundwater balance or flow, accelerating erosion around infrastructure defects. As Thailand approaches the rainy season following the March earthquake, it is crucial to conduct thorough cavity investigations during and after this period to prevent frequent large-scale land collapses.

6. Conclusions

In our pilot 338 km study exploring the application of GMS3 technology in and around Bangkok, Thailand, we obtained the following insights:

1. Analysis across the three generational zones of Bangkok indicated Gen.3 had the lowest detection rate (0.50), comparable to Japan's main road detection rate (0.44), whereas Gen.1 and suburban roads had 1.76 and 1.83 times higher rates, respectively; Gen.2 had the highest detection rate, 3.22 times that of Gen.3, likely due to factors such as infrastructure density, construction activities, and historical infrastructure quality variations.
2. The study's comprehensive assessment of cavity detection rates across various road categories in Thailand revealed no statistically significant differences between urban main roads, urban sub-roads (soi roads), and suburban main roads, with respective detection rates of 0.92, 0.94, and 0.93, we did not recognized significant difference in those categories.
3. A notable finding was the elevated detection rate of 1.21 in the first lane of urban main roads, which is 2.10 times higher than that of internal lanes (0.57), while suburban main roads showed a first lane detection rate of 2.12, 5.32 times greater than internal lanes (0.40), indicating a heightened risk of cavity formation in the first lane.
4. Of the 313 identified possible cavity locations, analysis of 224 cavities revealed that 73 (32.7%) were located beneath the concrete pavements, demonstrating the effectiveness of GMS3 technology on concrete surfaces, particularly in suburban main roads. This highlights the high demand for specific risk assessment methodologies for concrete pavements in Thailand.
5. The pilot application of GMS3 technology for detecting cavities in Thailand's public roads highlights its utility for road asset management, enabling the effective visualization of subsurface features up to 1.5 m deep, regardless of the road pavement structure.
6. The March 2025 Myanmar earthquake, which notably affected Bangkok's high-rise buildings due to the city's vulnerable alluvial soil, underscores the necessity for comprehensive cavity investigations near subsurface drainage infrastructure, where studies have shown an increased occurrence of subsidence and cavities post-seismic events, as Thailand enters the rainy season, to avert potential large-scale land collapse.

This study provides a critical foundation for future research, recommending that subsequent investigations in Bangkok's urban areas incorporate detailed subdivisions based on historical road development and comprehensive maintenance records. Such an approach will facilitate the creation of detailed heat maps of cavity occurrences and support the development of more effective road asset management strategies.

Acknowledgement

We would like to express our sincere gratitude to the data analysis team at Canaan Geo Research Co., Ltd., including Koji Tanida, Shoichiro Fujita, and José Rodrigues Neto, for their invaluable contributions to this research. Their expertise in subsurface radar data analysis provided critical insights that significantly enhanced the quality of this study. We are also deeply appreciative of their support in data interpretation, which was essential to the success of the project.

Additionally, we extend our heartfelt thanks to Mr. Smith Siricourop, Managing Director of Devotion Project Management Co., Ltd., as well as engineers Mr. Saivarun Rojkijjanurak and Mr. Thanapat Puntavong, for their cooperation during the field survey activities in Thailand. Their support was instrumental in facilitating the successful execution of this research.

References

[1] THAI NEWSROOM. (September 11, 2022). Sections Of Chaeng Wattana, Samut Prakan Roads Subside. (Available at https://thainewsroom.com/2022/09/11/sections-of-chaeng-wattana-samut-prakan-roads-subside/)

[2] Thai PBS News. (August 8, 2024). เปิด 3 สาเหตุ ถนนแจ้งวัฒนะ 2 ปี ทรุดตัว 8 ครั้ง - คืนนี้ตีสาม – Thai PBS news. (Available at https://youtu.be/WEtdOc9PRms)

[3] Yoshii, M. and Fukuda, A. (1994). The transition of urban structure in terms of transportation system in Bangkok, Thailand. *Civil Engineering History Research*, 14, pp. 149-157.

[4] Babel, M.S. and Das Gupta, A. (2006). Land subsidence: A consequence of groundwater over-exploitation in Bangkok, Thailand. *International Review for Environmental Strategies*, 6, pp. 307-328.

[5] Eddleston, M. (1996). Structural damage associated with land subsidence caused by deep well pumping in Bangkok, Thailand. *Quarterly Journal of Engineering Geology and Hydrogeology*, 29, pp. 1-4.

[6] Neto, J.R., Shinohara, J., Kato, Y., Tanida, K., Okino, A. and Sato, T. (2024). Advancements and applications of GMS3: a surface and subsurface unified database system. *Journal of Physics: Conference Series*, 2887, pp. 012022.

[7] Bangkok Post. (April 4, 2025). Unpacking Hidden Seismic Risks. (Available at: https://www.bangkokpost.com/opinion/opinion/2995371/unpacking-hidden-seismic-risks)

[8] Okamoto, J., Sera, R., Iwasa, M. and Ichii, K. (2024). Subsurface cavities under pavement due to large-scale earthquakes: characteristics and a proposal of non-destructive evaluation method. *Japanese Geotechnical Society Special Publication*, 10, pp. 2270-2273.