Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-1163

UAV-Based photogrammetry for displacement monitoring of temporary earth retaining structures: A novel approach to infrastructure management

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ABSTRACT: Temporary earth retaining structures in urban construction must be closely monitored to prevent collapses and ensure safety. Traditional point-based instruments including inclinometers provide only localized data and are costly and labor-intensive to install and measure. Therefore, this paper presents a novel UAV-based photogrammetric monitoring technique that overcomes the limitations by capturing overall displacements of temporary earth retaining walls with centimeter-level accuracy. The method was developed and tested at two urban excavation sites (Icheon, Songdo) encompassing various geotechnical conditions in South Korea. A UAV periodically captured high-resolution images of the retaining wall, which were used to create a dense 3D point cloud model. Wall displacements were subsequently computed between excavation stages, resulting in displacement heatmap obtained by rasterization using median values. Results showed that a low flight altitude (20 m) yields point cloud densities with 10^4–10^5 points/m² and sub-centimeter resolution, enabling accurate displacement detection. Higher altitude flights (≥40 m) produced significantly lower densities with 10^2–10^4 points/m² and led to overestimated displacements due to sparse data. At the test sites, the UAV approach recorded wall movements of less than 1 cm, which corresponded with inclinometer readings. In contrast, data from flight altitude exceeding 40 m did not accurately reflect the ground truth movements. This UAV-based approach offers a practical, wide-area monitoring solution that can greatly enhance excavation safety management by providing comprehensive deformation insights for temporary retaining structures.

KEYWORDS: UAV, point cloud, retaining wall, displacement, excavation.

1 INTRODUCTION

Urban excavations often rely on temporary earth retaining walls to stabilize deep cuts in the ground (Esmaeili et al., 2019; Mao et al., 2023). Monitoring these structures is critical, as unexpected wall movements can result in potential failures. Conventional monitoring methods typically use point-based instruments such as inclinometers installed in the surrounding soil. However, inclinometer-based approaches have several drawbacks. They provide measurement data only along the instrument's line which is one-dimensional data. This means only a few discrete points on the wall are monitored, and critical deformation may not be observed.

To address these limitations, researchers have been exploring advanced remote sensing technologies for temporary earth retaining wall monitoring (Oats et al., 2017). Vision-based photogrammetry using unmanned aerial vehicles (UAVs) has emerged as a promising solution for capturing three-dimensional displacement over the entire structure (Park et al., 2022; Quinton & Regan, 2018). Photogrammetry involves taking overlapping images and processing them into a 3D model or point cloud of the scene. Prior studies have demonstrated that close-range photogrammetry can achieve displacement measurement accuracy with 1–3 cm when compared to traditional survey methods (Ko et al., 2025). For temporary earth retaining walls, this means photogrammetry could potentially detect movements with precision comparable to instruments. This method also covers the entire wall surface rather than isolated points. These advances indicate that UAV photogrammetry can be a cost-effective and accurate tool for geotechnical monitoring, aligning with broader trends in smart construction and infrastructure management.

This paper presents a novel UAV-based photogrammetric monitoring technique for temporary earth retaining structures. The study is to overcome the spatial limitations of point sensors by providing high-resolution, full-coverage displacement measurements of temporary earth retaining walls. The study established optimal UAV operation parameters, suggested a displacement monitoring process, and validated the process on two construction sites. Key performance metrics such as point cloud density and modeling accuracy were highlighted, and the calculated results were compared with traditional measurements. Ultimately, this study demonstrates how integrating UAV photogrammetry into geotechnical monitoring can significantly enhance the management of excavation-related infrastructure.

2 METHODOLOGY

2.1 *UAV Photogrammetry Workflow*

The proposed monitoring system employs a UAV equipped with a high-resolution digital camera to collect images of the temporary earth retaining wall at bi-weekly intervals according to excavation stages. To achieve the required accuracy for displacement detection, the UAV is flown at a low altitude close to the target geotechnical structures. Through preliminary tests, a flight altitude of 20 m above the top of the structure was determined to be optimal, balancing coverage and image resolution. At the altitude of 20 m, the camera can capture the wall face in fine detail. In this case, the sufficient image overlapping is necessary with forward and side overlapping ratio over 80%. Ground control points (GCPs) around the excavation site are also used to geo-reference and scale the model. The photogrammetric process then generates a dense 3D reconstruction from the overlapped photos. The photo data are processed using structure-from-motion (SfM) software to produce a three-dimensional point cloud of the temporary earth retaining structure for each survey epoch. Each model contains millions of points representing the target wall surface.

2.2 *Point Cloud Data Processing*

To monitor changes over time, robust nearest neighbor distance method was used to compute the displacement of the retaining wall between successive 3D models, as shown in Figure 1. First, an initial baseline model is established as the reference. Subsequent models from later excavation stages are then aligned to the baseline coordinate system. The displacement is then calculated as the distance between the corresponding points in the current and baseline model in perpendicular direction to the structure, as shown in Figure 2. A robust statistical filtering is then applied to remove outlier points. Once the filtering is performed, the algorithm divides the target structure into a grid of segments or cells with 1 m by 1 m. The median displacement value within each grid cell is taken as the representative movement of that portion of the structure. This results in a displacement map covering the entire wall, which can be visualized as a color-contoured heatmap where cooler colors indicate minor displacement, and warmer colors highlight larger displacement.

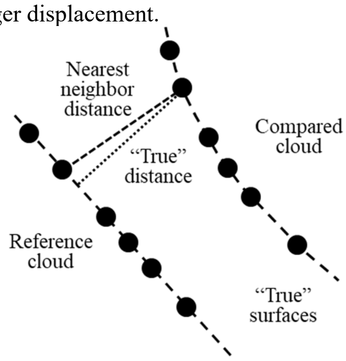

Figure 1. A robust nearest neighbor distance algorithm.

Figure 2. UAV-based displacement monitoring direction.

2.3 *Field Implementation and Test Sites*

The methodology was implemented and evaluated at two construction project sites in South Korea, chosen to represent various urban excavation scenarios.

A temporary earth retaining wall was installed supporting an excavation approximately 9.3 m deep at Icheon site, as shown in Figure 3, 4, and Table 1. This site was used in early 2024 to establish UAV survey standards. Multiple UAV flights were conducted at different altitudes of 20 m, 40 m, and 100 m above the target structure. It was performed to assess how flight altitude affects the model quality and displacement detection. Inclinometer sensors installed in the surrounding ground served as a baseline for comparison. The data from Icheon were critical in calibrating the photogrammetric model accuracy and validating that the UAV method could extract displacements within acceptable measurement criteria.

Figure 3. Excavation process of temporary earth retaining wall at Icheon site.

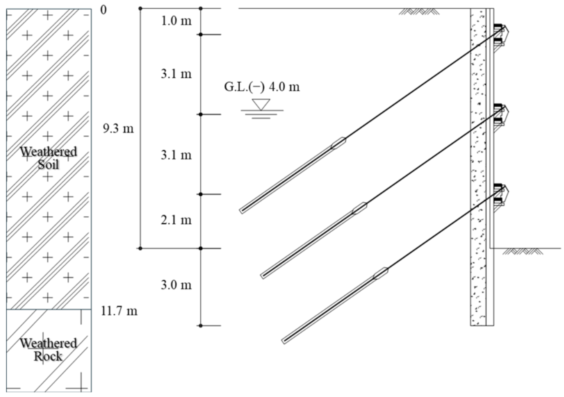

Figure 4. Cross section of temporary earth retaining wall and soil profiles at Icheon site.

Table 1. Types and specifications of temporary earth retaining structure at Icheon site.

Category	Type	Specification
Earth retaining wall	H-Pile, Earth plate	H-300×300×10×15 (C.T.C 1,800)
Ground anchor	Removable earth anchor	P.C Strand Ø12.7×4EA
Water cut-off method	E.G.M grouting	Ø600 (C.T.C 500)

Additional site was used in late 2024 at Songdo site for full-scale field validation of the monitoring system. The temporary earth retaining walls span a hundred meters, and multiple levels of excavation were carried out in stages with earth anchors installed, as shown in Figure 5, 6 and Table 2. The UAV was deployed bi-weekly according to the end of each excavation stage to capture the wall movement. Multiple UAV flights were conducted at different altitudes of 20 m, 60 m, and 100 m above the target structure to assess how flight height affects the model quality and displacement detection.

Throughout all site implementations, the captured data were processed with the same monitoring process. The detailed displacement heatmaps were then compared against traditional measurements using inclinometers for validation.

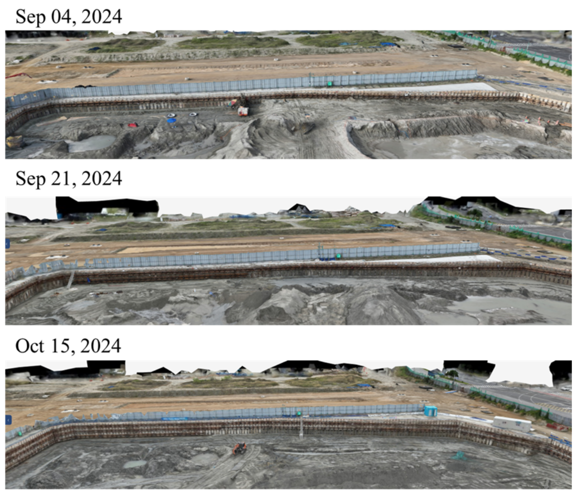

Figure 5. Excavation process of temporary earth retaining wall at Songdo site.

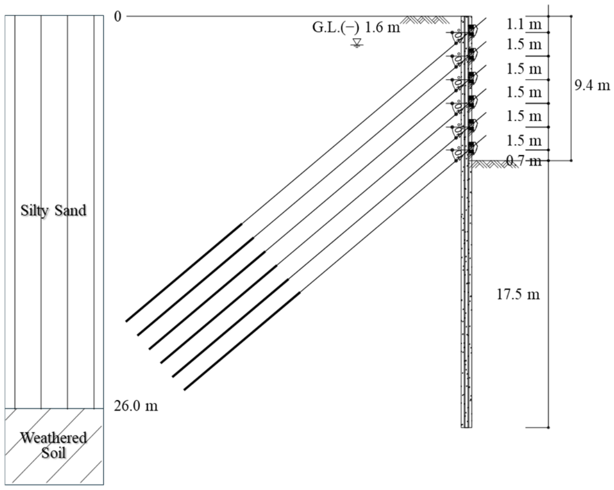

Figure 6. Cross section of temporary earth retaining wall and soil profiles at Songdo site.

Table 2. Types and specifications of temporary earth retaining structure at Songdo site.

Category	Type	Specification
Earth retaining wall	H-Pile, S.C.W	H-300×300×10×15 (C.T.C 900), S.C.W-Ø550(C.T.C 450)
Ground anchor	Removable earth anchor	P.C Strand Ø12.7×4EA

3 RESULTS

3.1 *Data Quality of UAV Photogrammetry*

The altitude analysis at the Icheon site was performed to compare the point cloud density, qualitative model accuracy. Table 3 summarizes the calculated photogrammetric model characteristics for various UAV altitudes. At the low altitude of 20 m, the data yielded a dense point cloud up to 23,000 points per square meter, corresponding to an average point spacing of ~0.7 cm. This high density means the model can resolve fine details of the wall surface and displacements with centimeters can be detected. In contrast, at 100 m altitude, which represents a typical altitude for entire site surveying in one flight, the point density fell to 100–200 pts/m². It shows only 9–10 cm point spacing, which leads to poor results of wall movements.

Table 3. Comparison of photogrammetric modeling outcomes at different UAV flight altitudes.

Flight Altitude (m)	Point Cloud Density (pts/m^2)	Avg. Point Spacing (cm)	Model Quality / Accuracy
20	*~ 23,000*	~ 0.7	Excellent (cm-level accuracy)
40	*~ 9,500*	~ 1.0	Moderate (1-2 cm accuracy; some noise)
60	*~ 2,500*	~ 2.0	Poor (overestimates displacement)
100	*~ 150*	~ 9.3	Poor (unable to detect <5 cm moves)

The altitude of 20 m achieves the highest point density and accuracy. higher altitudes cover larger areas faster but with reduced detail and accuracy. Moreover, the analysis found that lower point density not only reduces precision but can introduce spurious deformation signals. The algorithm's median-based comparison became sensitive to outliers and noise, causing an overestimation of displacement in the altitudes over 40 m. The 100 m data at Icheon indicated up to ~2–3 cm of apparent wall movement, whereas ground truth displacement data of wall was nearly stable, clearly a false alarm caused by insufficient resolution. In contrast, the 20 m data correctly showed the wall movement to be under 1 cm, consistent with the inclinometer readings, which recorded approximately 1.6 mm of deflection at that stage, as shown in Table 4. The 40 m altitude results were still high, showing 1–2 cm displacement that was not corresponding with by instruments.

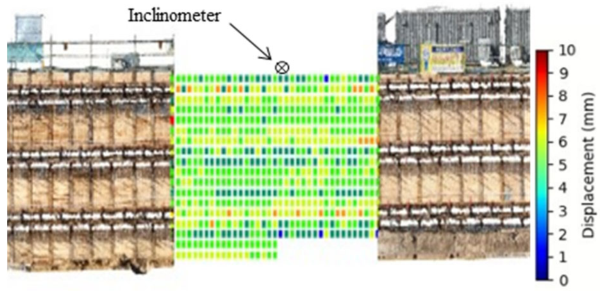

Figure 7. UAV-Based displacement monitoring results with flight altitude of 20 m at the Icheon site.

Table 4. Measurement results and evaluation for the management criteria at Icheon site.

Category	Measurement (mm)	Measurement criteria (mm)	Evaluation
Inclinometer	*1.6*	18.6	Stable
UAV	*0~6.0*		Stable

3.2 *Displacement Monitoring*

Using the 20 m flight altitude standard, the UAV-based system was deployed for continuous monitoring at the Songdo site. At Songdo site, which involved a deep excavation with six levels of earth anchor, the UAV was flown at bi-weekly intervals to capture the temporary earth retaining wall deformations as the excavation advanced. The photogrammetric analysis produced displacement heatmaps for each stage. The maximum lateral displacement observed at the final excavation depth was 6 mm at a particular corner of the wall. Wall displacement of most areas only moves 0–2 mm, reflecting a very stable retaining system, as shown in Figure 8 and table 5. These magnitudes were in line with the project's inclinometer data and well below the measurement criteria for the target retaining wall.

These findings demonstrate that UAV-based photogrammetry enables displacement monitoring with accuracy within a few millimeters, which is adequate for the early detection of potential trends in wall behavior. Notably, this degree of precision, previously achievable only through extensive installation of conventional instruments such as inclinometers. However, the UAV-based monitoring process can provide the entire surface monitoring of the retaining wall using a single UAV deployment.

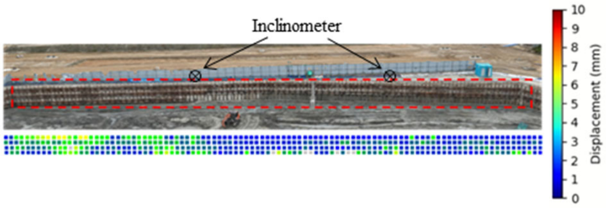

Figure 8. UAV-Based displacement monitoring results with flight altitude of 20 m at the Songdo site.

Table 5. Measurement results and evaluation for the management criteria at Songdo site.

Category	Measurement (mm)	Measurement criteria (mm)	Evaluation
Inclinometer	*2.8 (Average)*	18.8	Stable
UAV	*0~6.0*		Stable

4 CONCLUSION

This study introduced a novel approach to infrastructure management for excavation projects: UAV-based photogrammetry for displacement monitoring of temporary earth retaining structures. By using UAV-based imagery and 3D modeling, the method provides a comprehensive, high-resolution view of geotechnical structure's behavior that addresses the limitations of traditional point-based instrumentation. Whereas inclinometer sensors only sample a few points and require significant labor, the UAV system can survey the entire wall and detect movements across every portion of the structure with centimeter-level accuracy. The study demonstrated the feasibility and benefits of this approach at real construction sites. Key findings include:

1. The UAV photogrammetric technique successfully measured wall displacements in the range of a few millimeters to centimeters. The result also matches well with the result of conventional instruments installed in surrounding soil. This approach enables detection of non-uniform deformation patterns of temporary earth retaining walls that cannot be observed by sparse sensors.

2. Through comparative tests, a low flight altitude of 20 m was identified as optimal for obtaining the dense data needed for accurate displacement extraction. While such close-range flights entail more images and longer processing, the study showed that flight altitude over 40 m shows significant large point density that leads to overestimation of displacement analysis.

3. UAV-based monitoring can complement existing sensor data by providing an independent, visual verification of wall performance. The UAV method can also enable reliable daily or weekly measurements, which is a significant improvement in frequency and coverage, ultimately contributing to early warning capabilities of infrastructures.

In conclusion, UAV-based displacement monitoring process represents a novel and powerful tool for geotechnical infrastructure monitoring. This study emphasizes that the technique is practical for routine use in urban excavation projects with proper workflow optimizations. By using the suggested workflow, potential issues with temporary retaining structures can be detected in advance and mitigated before escalating into failures. Future work will focus on further streamlining the process such as AI-based feature recognition to enhance automation and improving data processing speeds with comparative analysis of filtering methods. Additionally, expanding field trials to more diverse conditions such as different wall types is needed to build robust approach for monitoring geotechnical structures.

5 REFERENCES

Esmaeili, F., Ebadi, H., Saadatseresht, M., & Kalantary, F. 2019. Application of UAV photogrammetry in displacement measurement of the soil nail walls using local features and CPDA method. *ISPRS International Journal of Geo-Information*, *8*(1), 25.

Ko, S. J., Hong, S., Kwak, T. Y., Gu, K. Y., & Kim, S. R. 2025. UAV LiDAR–based 3D point cloud data processing for monitoring consolidation settlement during construction: a case study in Busan, South Korea. *Environmental Earth Sciences*, *84*(13), 362.

Mao, Y., Zhang, X., Cao, W., Fan, S., Wang, H., Yang, Z., ... & Bai, Y. 2023. Research on the Health Assessment Method of the Safety Retaining Wall in a Dump Based on UAV Point-Cloud Data. *Sensors*, *23*(12), 5686.

Oats, R. C., Escobar-Wolf, R., & Oommen, T. 2017. A novel application of photogrammetry for retaining wall assessment. *Infrastructures*, *2*(3), 10.

Park, H. C., Rachmawati, T. S. N., & Kim, S. 2022. UAV-based high-rise buildings earthwork monitoring—A case study. *Sustainability*, *14*(16), 10179.

Quinton, D., & Regan, T. J. 2018. *Use of Unmanned Aerial Systems (UAS) by State DOTs February 27, 2018 Peer Exchange* (No. FHWA-HIF-18-060; DOT-VNTSC-FHWA-19-1). United States. Federal Highway Administration.