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Displacement Measurement of Soil Nail Walls using Close Range Photogrammetry

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Abstract

Displacement measurement of the soil nail walls is very important in monitoring the slightest movements in excavations to prevent disastrous accidents like wall collapsing. Usually in building construction projects, the micro-geodesy and instrumentation methods are used in measurement of vertical and horizontal movements of the walls. Limitations like high cost, long time, limited accuracy, low flexibility and high dependence on the project conditions are the causes of the low control on the movements of walls in many projects. Unfortunately in some cases adverse accidents occurs because of this reason. In this research, for the first time, the use of close range photogrammetry in displacement measurement of the soil nail walls has been proposed and experienced. For this purpose, a photogrammetric system has been designed and examined on a building construction project in Tehran, Iran. The results of monitoring of one the suspicious walls in the project in different time epochs of the excavation and its comparison with the consequences of the micro-geodesy method confirmed the accuracy of the proposed method (7.7mm). According to this fact that the proposed method has solved the many limitations of the traditional methods, the close range photogrammetry as an efficient method is introduced as an alternative to the existing method in construction projects.

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Keywords: calibration; close range photogrammetry; displacement measurement; network design; soil nailing.

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1. Introduction

The soil nailing method is used to retrofitting the embankments and stone walls. This method includes excavation of horizontal holes in the tranche, placing the nails into these holes, injection of the slurry cement and implementing the shotcrete on the surface of the tranche.

According to the importance of the excavation projects in urban areas and the high confidence level of the wall containment using soil nailing method, this approach has been widely used in the past decade. In order to ensure the good operation of the implemented wall containment method and preventing accidents, the movements of the hazardous walls are measured in the different time epochs during excavation.

Usually the micro-geodesy and instrumentation methods are used in the measurement of vertical and horizontal movements of the walls. Limitations like high cost, long time, limited accuracy, low flexibility, high dependence on the project conditions, need to the skilled personnel are the causes of the low control on the movements of walls in many projects.

The close-range photogrammetry is the technique of three dimensional measurements of physical objects using two dimensional images. The use of photogrammetric techniques for measurement of the behavior and movements of the structures significantly growth with development of the autonomous digital close-range photogrammetric systems in the middle of the 90s. As a deformation measurement tool, the close-range photogrammetry has some particular advantages. Some the most important features of this method are: no direct contact with objects, high speed imaging, easy access to affordable digital cameras, automatic data processing system with easy operation, capability of using this approach for objects with different dimensions and high flexibility in accuracy assessment (John et al. 2007, and Ruinian and David 2010).

In this research for the first time, a close-range photogrammetric system has been used in monitoring the soil nailed walls. The tools used in this system for measurement of the large scale objects (larger than 10 m) includes: non-metric digital camera, photogrammetric targets, scale bars and the close-range photogrammetry data analysis software. Moreover, for accuracy assessment of the outputs and control points measurements a total station camera has been used.

For designing and implementing the close-range photogrammetric system four main components including camera selection, camera setting and targeting, camera calibration, designing the network (the base coordinate system and scale) and imaging, calculations, analysis and resultant outputs are required. Designing and implementing the mentioned system based on the specific circumstances of the construction projects have been described here after.

2. Materials & Methods

Within the projects with soil nailed walls, the excavation is performed step by step. In each stage, the soil nailing system which is designed beforehand by civil engineers matching the project situations is implemented. Figure 1, depicts three stages of excavation in a four-month time epoch in the studied construction project located at the Velenjak Avenue in Tehran, Iran.

(a)

(b)

(c)

Figure 1. The progress of studied construction project

Many parameters are considered in designing a soil nailing system in a project. Among these parameters, the soil type, amount of surcharge loading, wall slopes, ground water, restriction of adjacent properties, the height of the walls and so on could be mentioned.

During all stages of the excavation and then, the soil nailed wall and the soil behind are inclined to transform toward the scoop.

As it is mentioned in the FHWA regulation, the maximum horizontal and vertical displacement over a soil nailed wall is calculated based on the height of the walls using equation 1 (Carlos and Victor 2003):

$$\delta h = (\delta h/H)i \times H \quad (1)$$

In the above equation, the δh is the maximum of horizontal displacement over the wall, H is the height of the wall and the (δh/H)i is the soil type dependent coefficient extracted from table 1.

Table 1. values of (δh/H)i coefficient as a function of soil condition (Carlos and Victor 2003)

Variable	Weathered Rock and Stiff Soil	Sandy Soil	Fine-Grained Soil
(δh/H)i	1/1000	1/500	1/333

The predominant soil type of this project, based on the beforehand speculations, was determined as sandy soil (Sarnag 2010). The depth of the excavation is about 25 m. Based on the equation 1 and table 1 the maximum displacement measurement over the wall has been predicted about 5cm (the maximum displacement occurs over the walls).

If the measured displacement exceeds the predicted one, the project is exposed to serious hazard and preventive actions must be performed.

In close-range photogrammetric measurements the camera is the most important facility. In this study, the Fujifilm Digital Camera FINEPIX HS20EXR has been used (a non-metric digital manual camera with Manuel setting for focal length and all the radiometric parameters). The CMOS sensors (4.8 × 6.4 nm) with 16 megapixel resolution are used this camera (Figure 2).

Figure 2. the non-metric digital camera Fujifilm FINEPIX HS20EXR

The retro-reflective targets located on the walls have been used as measurement points. Based on experimental rules, for each 1 m distance from the object, 2mm is added to the dimension of the targets. Therefore, for the imaging, 14 and 16 mm targets have been used. The 16 mm targets are located as the basic targets at the northeast wall of the project (80 m distance from the camera) and the 14 mm targets are located at the top of the soil nailed wall (60 m distance from the camera) (figure 3).

Figure 3. The layout of mounted targets and their role

In order to calibrate and determining the internal orientation parameters of the camera a test field with dimensions proportional to the object dimension has been used. In the network designing and target locating step, according to the restrictions of the project, the maximum number of targets coverage in the images and the convergence of the camera stations were considered.

Solving the limitations of imaging space and the network stability to achieve the desired accuracy were provided using the concept of hyper redundancy (increasing the number of stations and images in each station). Figure 4 shows the created network between the imaging stations and the object.

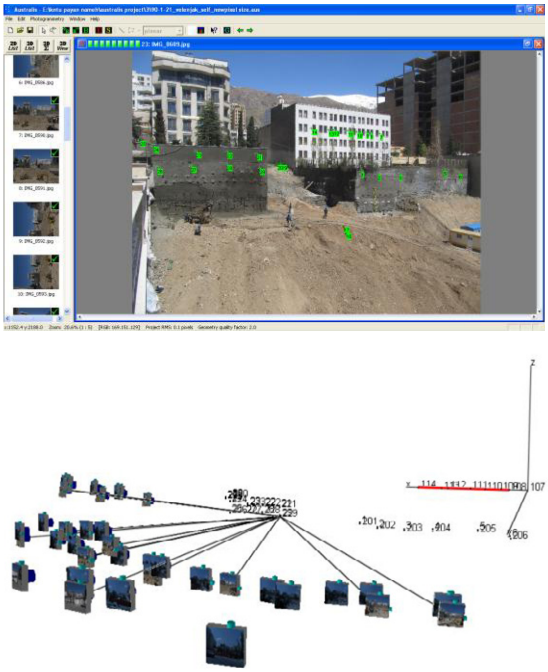

Figure 4. Geometry of the networks and targets

The target local coordinates were determined using a bundle adjustment of the close range photogrammetry network. In order to create a common coordinate system between two epochs a new method for simultaneous adjustment of the two networks using common targets were implemented.

The resulted network of the first epoch with the specific internal orientation parameters with the resulted network from the second epoch with its internal orientation parameters were entered to the adjustment process simultaneously. The coordinates of the constant and displaced targets were determined using each epoch images. This new method was called "Combined Photogrammetry Deformation Adjustment" or "CPDA".

Thus in the output of this method a coordinate set for constant targets and two coordinate sets for displaced targets in a common coordinate system were determined. These two coordinate sets belong to the first and second epoch. The amount of displacement is the differences between two sets of coordinates. A scale bar was used to transform the local coordinates to the real scale.

Overall, in the designed system the circular retro-reflective targets which the centers are uniquely detectable on the images are located on the objects. The imaging is performed based on the converged network design parameters. The coordinates of targets are calculated based on the co-linearity condition using bundle adjustment. Then the coordinates of the targets are transformed to real scale using only a scale bar without a control point. Therefore, in each epoch a set of coordinates with determined accuracy are calculated for targets. Comparing the coordinates of targets in different epochs, the amount of displacement in each epoch is estimated. The coordinates of the these points have been measured at the beginning of the project using total station camera with angular accuracy of 2 seconds and distance measurement accuracy of 2mm ± 2 ppm based on a micro-geodesy network outside the excavation area. The set of measurements on the images and calculations have been performed using close-range photogrammetry software, Australis 7.3 and MATLAB. The implementation procedure of the proposed method is depicted in Figure 5.

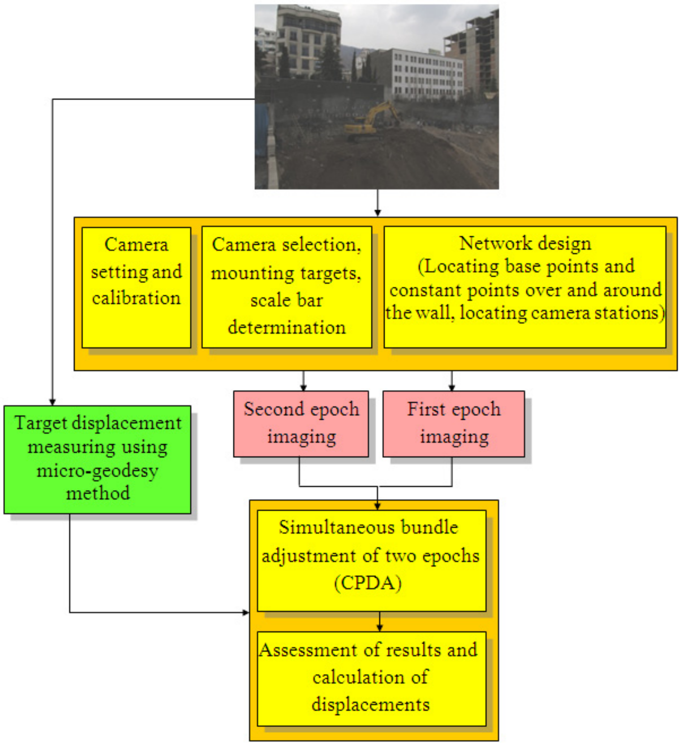

Figure 5. Procedure of the proposed method

3. Results and Discussion

The displacement measurement of one the suspicious walls of the project is performed in 2 time epochs within 4 months. The coordinates of the mounted targets on the wall have been calculated using both micro-geodesy and close-range photogrammmetry methods.

The results of micro-geodesy method according to the network and the instruments accuracy and the project limitation in the worst condition were calculated about 5mm. The accuracy of coordinates resulted using close range photogrammetry method after performing bundle adjustment was calculated as 3mm. The displacement of targets (Figure 3) measured using microgeodesy and close-range photogrammetry are described in table 2.

In order to investigate the accuracy and precision of the proposed photogrammetric method, the mean of Absolute Average Differences (AAD) of the measured coordinates were calculated in each two epoches.

Table 2. Differences of targets displacement in photogrammetry and micro-geodesy method (meter)

Wall Name	Target Name	Displacement (Microgeodesy)	Displacement (Photogrammetry)	Diff. From Microgeodesy & Photogrammetry	Mean Displacement Of Wall (Microgeodesy)	Mean Displacement Of Wall (Photogrammetry)
Right Wall	TAR1	0.029	0.038	-0.009	0.026	0.031
	TAR2	0.024	0.031	-0.007		
	TAR3	0.024	0.025	-0.001		
Left Wall	TAR21	0.029	0.031	-0.002	0.031	0.034
	TAR22	0.031	0.024	0.007		
	TAR23	0.034	0.028	0.006		
	TAR24	0.032	0.043	-0.011		
	TAR26	0.029	0.044	-0.015		
	TAR27	0.033	0.046	-0.013		
	TAR28	0.030	0.024	0.006		
AAD		---	---	**0.0077**	---	---

According to equation 1 and the height difference about 20m between two epochs, the normal displacement was determined as 40mm for this wall in this step. A quick method for monitoring the suspicious walls is vital in construction projects. According to this goal, the accuracy of close-range photogrammetric method is calculated about 7.7 millimeter as shown in table 2. The right wall had a mean displacement about 31mm and the left wall had a mean displacement about 34mm toward the scoop within two epochs of measurements. The imaging was performed in about 1 hour in a convergence network design. The stability condition in close range photogrammetry network was provided using 40 to 50 images in each time epoch.

In micro-geodesy method used for accuracy assessment in this method, one full work day was spent in each time epochs for collecting the length and angle observations in addition to the high cost of equipments.

According to features of the proposed method including: being independent from control points and micro-geodesy measurements, simplicity of performance, speed of the performed system and the ability to reach under 1cm accuracies, this method is introduced as an ideal approach in displacement measurement of the excavation walls.

Some of other advantages of the close-range photogrammetric method are: monitoring to the last minute of wall collapsing, no direct contact with the objects, the ability of measuring many points of the objects simultaneously, visual documentations, repeating the measurements, the ability of measuring irregular and complex walls with high degree of freedom and the low cost. Among the limitations of this method the need to protecting targets from Shotcrete covering should be noticed.

4. Conclusion

The proposed close-range photogrammetric system in this research includes a non-metric digital camera (Fujifilm HS20), retro-reflective targets, network design for placing camera stations and targets, scale bar, the new submitted CPDA method in simultaneous adjustment of all measurements in a common coordinate system and the increasing of the outputs accuracy. In this research, the time of imaging was less than 1 hour and the output accuracy was better than 8mm in object dimensions. The differences of mean displacements were calculated as 5mm for the right wall and 3mm for the left wall.

The monitoring of the walls in this method is simple and quick so the permanent and low cost monitoring of the walls would be possible for engineers. The large number of images leads to high degree of freedom and high confidence level of the results.

Therefore, implementing this method is recommended in monitoring of the construction projects as a suitable alternative to micro-geodesy method.

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