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Three-dimensional Numerical Study of the Effect of Convex Corners on the Displacements Induced by Excavation for Soil-Nailed Walls

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ABSTRACT: In most excavation projects, the excavation plan is irregular in shape, including concave and convex corners. In practice, the 2D (i.e., plane strain) analysis is often employed to evaluate the factor of safety and displacements induced by excavation for concave and convex corners. However, contrary to concave corners, using the plane strain analysis is not on the conservative side for convex corners. The present paper uses a numerical modeling methodology to study the effects of the convex corner on the displacements induced by excavation for soil-nailed walls. In this regard, a series of parametric studies are carried out, involving 2D and 3D deformation analyses of nine soil-nailed excavation models with three wall heights and three types of soil. The results of the paper show that the lengths of the affected zone (i.e., the zone adjacent to the convex corner along which the 3D settlements at the wall crest are higher than the 2D one) increase by decreasing the soil strength. Moreover, the results indicate that the maximum ratios of 3D settlement to 2D one along the affected zone are independent of the wall height and soil type. In addition, the results suggest that giving azimuth to soil nails along the affected zone causes the wall displacements along this zone to increase significantly.

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1. INTRODUCTION

In most excavation projects, the excavation plan is irregular in shape, including convex and concave corners. The three-dimensional geometry effects of corners cause special conditions for the design and construction of excavations. In practice, the plane strain (i.e., two dimensional) condition is usually assumed for the corners to avoid performing 3D deformation analyses. This assumption is on the safe side for the concave corners but could be non-conservative for the convex ones. A lot of research has been conducted to study the effects of convex corners on the pattern of wall displacements during excavation [1-8]. However, in most of them, the retaining structure was a diaphragm wall or a braced cut system. The present paper uses a numerical modeling methodology to examine the geometry effects of convex corners on the displacements of a soil nailed wall, which has been less studied in the past.

2. METHODOLOGY

In the present study, 2D and 3D deformation analysis of 9 soil-nailed walls with three heights of 10, 15, and 20m and three soil types of weak, medium, and strong were performed. For each soil-nailed wall, first, the initial soil nails design involving the soil nails arrangement, soil nails lengths, and diameters were determined using the FHWA guidance [9]. Then the factor of safety (FOS) of the soil-nailed wall was calculated using the GeoSlope software and if it was necessary, the initial soil nails design was modified to achieve the minimum design FOS of 1.35. Afterward, the 2D deformation analysis of the soil-nailed wall was performed using the FLAC3D software. The soil nails design was revised again if the maximum horizontal displacement or settlement was higher than the allowable value (herein 0.003H where H is the height of the wall). Finally, the 3D deformation analysis for the convex corner model of the soil-nailed wall with the same design as the 2D one was carried out. It should be noted that the soil nails were assumed to be perpendicular to both sides of the convex corner (i.e., the soil nails had no azimuth).

Fig. 1 compares the 2D and 3D contours of settlement for the 10m soil-nailed wall with the weak soil. It can be seen that by approaching from the boundaries to the corner tip, the 3D settlements of the soil-nailed wall increase considerably compared with the 2D one. This could be attributed to the 3D geometry effects of the convex corner.

3. RESULTS AND DISCUSSION

To study the effects of the convex corner on the settlements of the soil-nailed walls, a parameter called the plane strain ratio (*PSR*) for settlement is employed. The *PSR* for settlement (called hereafter the *PSR* for the sake of brevity) is defined as the ratio of 3D settlement to 2D one. The zone at the vicinity of the corner tip along which the 3D settlements are higher than the 2D one (i.e., *PSR*>1) is defined as *the affected zone*. The length of the affected zone for the 10m model with the weak soil is depicted in Fig. 1, which is equal to two times the wall height (i.e., 2H).

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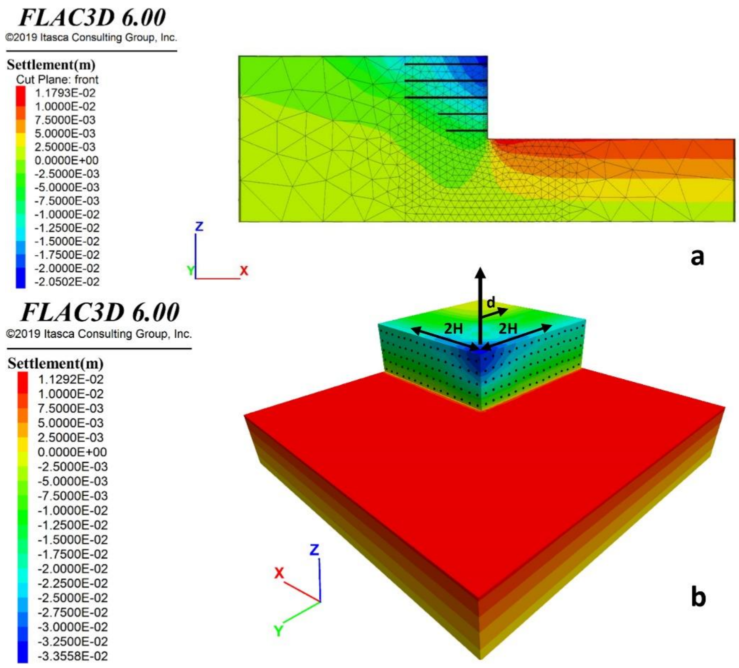


Fig. 1. The 2D (a) and 3D (b) contours of settlement for the 10m soil-nailed wall with the weak soil

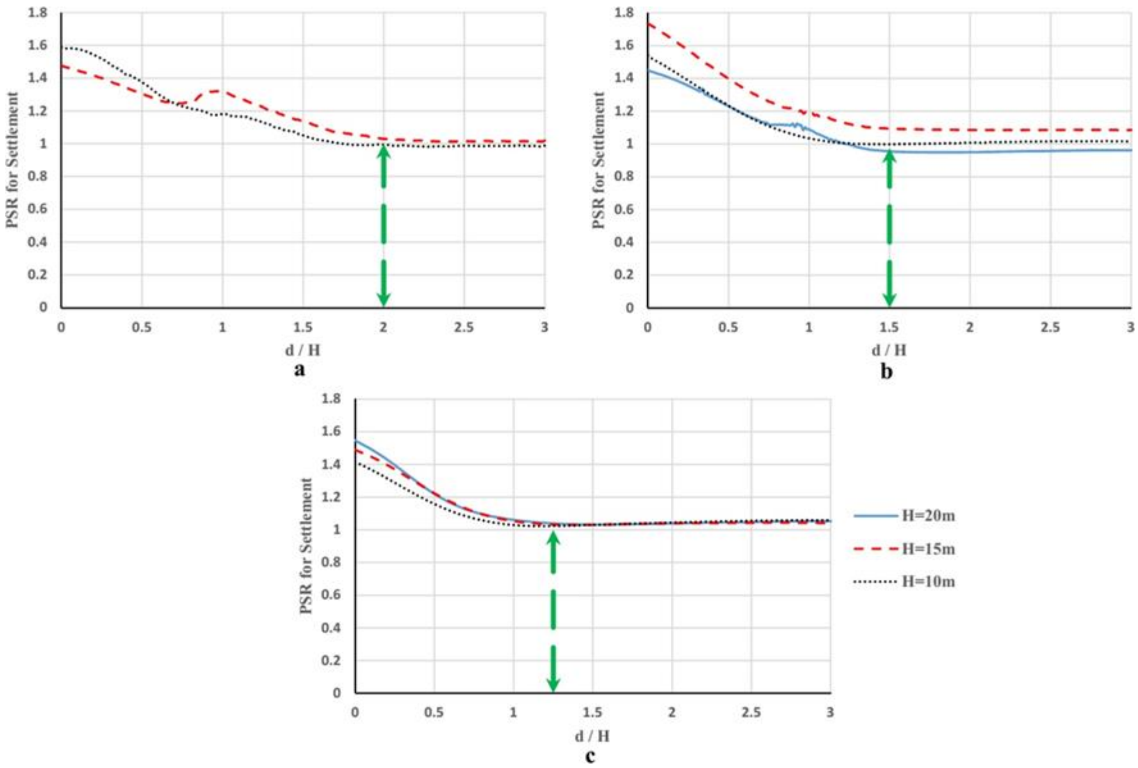
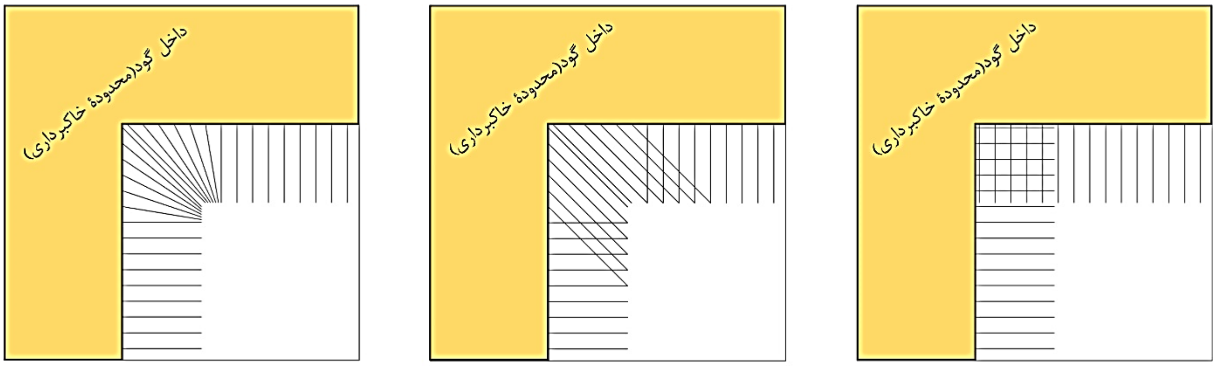


Fig. 2. Variations of *PSR* values versus *d*/*H* for the models: a) Weak soil b) Medium soil c) Strong soil

Fig. 2 shows the variations of *PSR* values versus *d*/*H* for the models, where d is the distance from the corner tip. The lengths of the affected zone for various models are depicted in the charts by the vertical dashed lines. It can be seen that the lengths of the affected zone for the weak, medium, and strong soils are equal to 2*H*, 1.5*H*, and 1.25*H*, respectively. This indicates that the length of the affected zone depends on the soil type and increases by decreasing soil strength. Moreover, it can be observed that the maximum *PSR* values (i.e., the *PSR* values at *d*=0) do not vary remarkably by the soil type and



c b a

Fig. 3. Various modes for soil nails azimuth in the affected zone: a) No azimuth, b) Constant azimuth, and c) Variable azimuth

Table 1. The maximum *PSR* values for various azimuth modes (the 15m model)

Type of soil	Maximum *PSR*		
	No azimuth	Constant azimuth	Variable azimuth
Weak	1.48	29.47	10.2
Medium	1.73	8.3	4.93
Strong	1.49	4.56	3.11

wall height; they are on average equal to 1.5. Accordingly, it can be said that the 3D deformation analysis is required for the convex corner of a soil-nailed wall. However, if the 2D analysis is employed, it could be suggested that 1.5 times of the estimated 2D settlement is controlled by the allowable settlement in the design process.

To investigate the effects of soil nails azimuth on the maximum *PSR* value along the affected zone, the convex corner model of the 15m soil-nailed wall was analyzed with three azimuth modes depicted in Fig. 3: *no azimuth* (the default mode of the present study), *constant azimuth* (the azimuth of soil nails is equal to 45 degrees in the affected zone) and *variable azimuth* (the azimuths of soil nails vary from zero to 45 degrees in the affected zone). Table 1 compares the maximum *PSR* values for the three abovementioned modes. It is obvious that giving azimuth to soil nails causes the wall settlements increase significantly.

4. CONCLUSION

The present paper adopted a numerical modeling methodology to study the geometry effects of convex corners on the deformation of soil-nailed walls. In this regard, 2D and 3D deformation analyses of 9 soil-nailed walls with three heights and three types of soil were performed using the FLAC3D software. Then the 2D and 3D settlements for the models were compared using a parameter called the *PSR* (i.e., the ratio of 3D settlement to 2D one). The main conclusion of the present paper are as follows:

1. The length of the affected zone (the zone at the vicinity of the corner tip along which the 3D settlements are higher than the 2D one; in other words, *PSR*>1) depends on the soil type in the way that it decreases by increasing soil strength. The lengths of the affected zone for the weak, medium, and strong soils are equal to 2*H*, 1.5*H*, and 1.25*H*, respectively.

2. The maximum *PSR* values along the affected zones do not depend on the soil type and wall height, being on average 1.50. Accordingly, if 3D deformation analysis for the convex corner model of a soil-nailed wall is not conducted in the design process, instead, the 1.5 times of the 2D settlement could be controlled by the allowable settlement. From an engineering viewpoint, this criterion is on the safe side.

3. Giving azimuth to the soil nails in the affected zone increases displacements considerably and is not recommended at all.

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