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2D AND 3D FEM ANALYSIS IN GEOTECHNICS: WHEN DOES THE THIRD DIMENSION MATTER?

Dora BELOŠEVIĆ[1]

ABSTRACT

Finite Element Method (FEM) is widely used in geotechnical engineering for analyzing soil-structure interactions, slope stability, and foundation performance. While 2D FEM is a common approach due to its efficiency and simplicity, 3D FEM provides a more realistic representation of geotechnical problems by incorporating the third spatial dimension. This study compared the results of 2D and 3D FEM analyses to determine whether the inclusion of the third dimension significantly affects computational outcomes for the same geotechnical model.

To investigate this, two case studies are conducted: (1) a slope stability analysis in both 2D and 3D, and (2) a settlement analysis in both 2D and 3D. The results show that problems that inherently follow a 2D assumption, such as slope stability, 3D modeling does not provide significant advantages, making 2D analysis a sufficient and efficient approach. However, settlement analysis is inherently a 3D problem due to stress distribution and spatial soil deformations, meaning that a 2D model cannot accurately capture real behavior.

The study highlights the importance of choosing the appropriate FEM approach based on problem characteristics. While 2D FEM remains a powerful tool for many geotechnical applications, complex deformation patterns and anisotropic effects in problems like settlement require 3D modeling for accurate predictions. These findings provide engineers with practical guidelines for optimizing computational resources while ensuring reliability in geotechnical design.

Keywords: Finite Element Method (FEM), 2D and 3D analysis, slope stability, settlement analysis.

LITERATURE REVIEW FOR SPT AND DCPT CORRELATIONS

The analyses in this paper were conducted in PLAXIS 2D and 3D softwares. PLAXIS is a finite element analysis (FEA), or finite element method (FEM) software developed for geotechnical engineering applications, enabling the simulation of soil-structure interaction under various loading and boundary conditions. It incorporated advanced constitutive models to capture the nonlinear, time-dependent behavior of soils. PLAXIS 2D is designed for plane strain or axisymmetric problems, where geometry and loading are consistent along one dimension. It is typically applied to the analysis of retaining structures, embankments, and shallow foundations where a two-dimensional approximation is valid.

PLAXIS 3D, in contrast, allows for full three-dimensional modeling, making it suitable for complex geometries and spatially variable loading conditions such as pile groups, tunnels, and excavations with irregular shapes.

In the following chapters, 2D and 3D calculations of slope (excavation) stability and settlement were analyzed, followed by a comparison of the obtained results.

SLOPE STABILITY ANALYSIS

The first 2D and 3D analyses were conducted on a wide excavation with a 2V:1H slope, partially excavated in soil (upper section) and predominantly in rock mass.

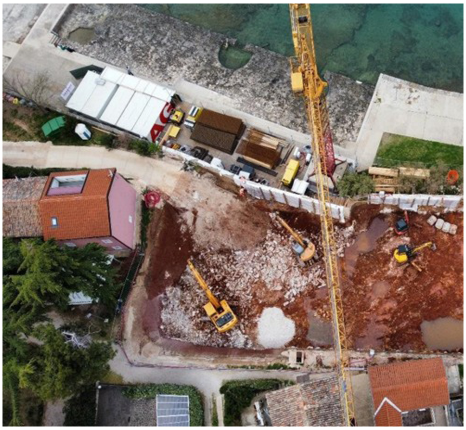

Figure 1 *Aerial view of the construction site*

1 2D and 3D FEM analysis in geotechnics: When does the third dimension matter?; Geotech d.o.o., Rijeka, Hrvatska, dorabelosevic3@gmail.com

As an additional load on the excavation, a roadway located at the top was considered. The total traffic load applied in the analysis was q_{ed} = 13,0 kN/m². Data obtained from exploration boreholes at the site confirmed that the groundwater level (in this case, the sea) is situated below the excavation level, and therefore has no influence on its global stability. The material properties adopted in both analyses (terra rossa and limestone) were obtained through site-specific investigative drilling and testing conducted at the project location.

The goal of the 2D and 3D analyses in the following calculations is to determine the global stability of the slope (excavation) and the overall displacements that occur due to the excavation and the effect of traffic load.

2D analysis

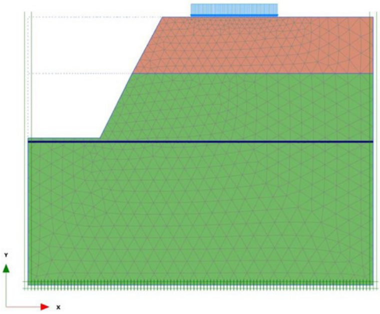

Figure 2 *2D model of the excavation with a 2V:1H slope*

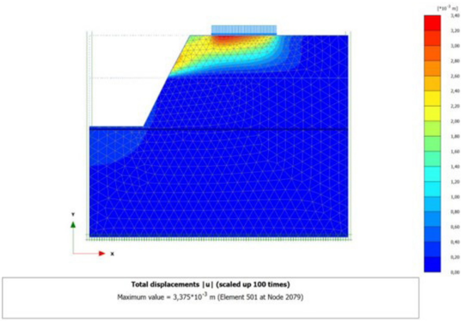

Figure 3 *Total displacements of the model in the serviceability limit state (SLS) phase*

The overall displacements of the model - both horizontal and vertical - are 3.375 x 10-3 m (approximately 3.4 mm), representing a minimal deformation in relation to the dimensions of the excavation.

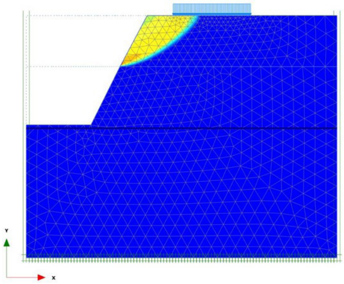

Figure 4 *Slip surface obtained for the 2D calculation model*

The slip surface occurs in the upper soil layer and terminates at the interface with the rock material. The global factor of safety obtained from the 2D analysis is FS = 1.81, which exceeds the threshold value of FS = 1.0.

The 2D analysis confirmed that the excavation is stable and that no additional support measures are required.

3D analysis

The 2D analysis assumes the "third dimension" to be infinitely long, effectively modeling the slope as a plane strain condition. In contrast, the 3D model incorporates the actual width of the design slope, allowing a more realistic spatial representation of the excavation geometry:

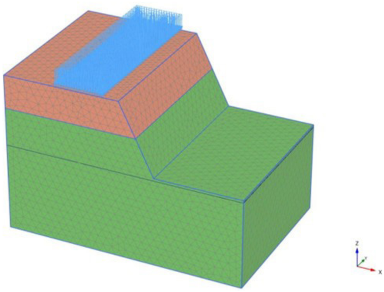

Figure 5 *3D model of the excavation with a 2V:1H slope*

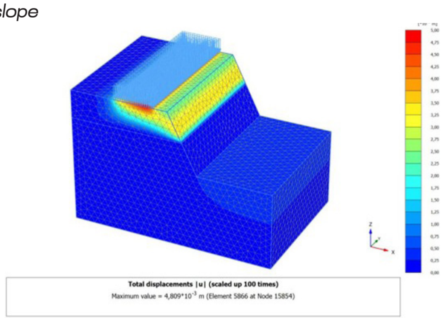

Figure 6 *Total displacements of the model in the serviceability limit state (SLS) phase*

The overall displacements of the 3D model – both horizontal and vertical – are 4.809 x 10^{-3} m (approximately 4.8 mm), also representing a minimal deformation in relation to the dimensions of the excavation.

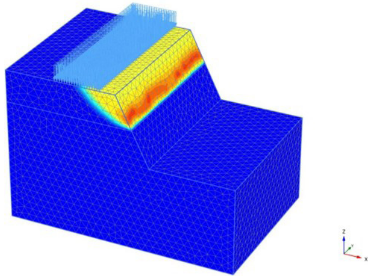

Figure 7 *Slip surface obtained for the 3D model*

The slip surface, as in the 2D analysis, occurs within the upper soil layer and terminates at the interface with the underlying rock mass. The global factor of safety obtained from the 3D analysis is FS = 1.83, which also exceeds the limit value of FS = 1.0, confirming overall stability.

SETTLEMENT ANALYSIS

The second 2D and 3D analyses were performed on a structural model consisting of a reinforced concrete footing connected to bored piles with a diameter D = 600.0 mm and a length of L = 5.0 mm. The footing, with plan dimensions of 2.70 x 2.70 m, is positioned beneath a column subjected to a vertical design load of F = 1605 kN.

The piles were bored through an upper layer of sandy soil into a deeper, more substantial gravel layer. Site investigations indicated that the groundwater table is situated precisely at the boundary between these two stratigraphic units.

2D analysis

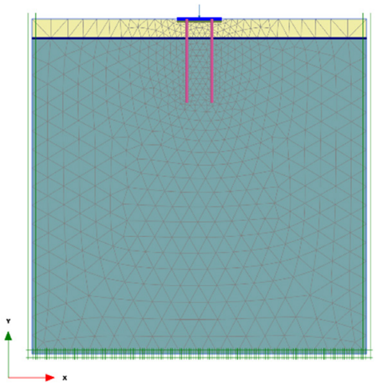

Figure 8 *2D model of the foundation slab and piles*

The overall settlements of the 2D model are approximately 19,5 cm.

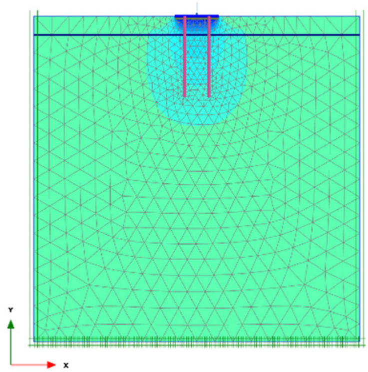

Figure 9 *Total settlements of the model for the SLS phase*

3D analysis

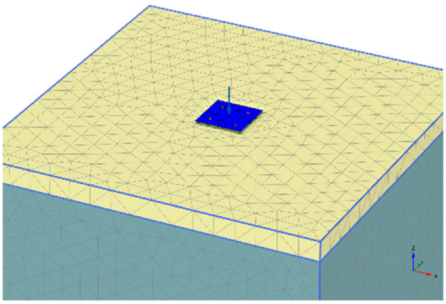

Figure 10 *3D model of the foundation slab and piles*

In the 3D analysis, the foundation slab was modeled with its third dimension (width) limited to 2.70 m rather than assumed infinite. Additionally, the piles were modeled as beam elements, accurately representing their number and layout within the system.

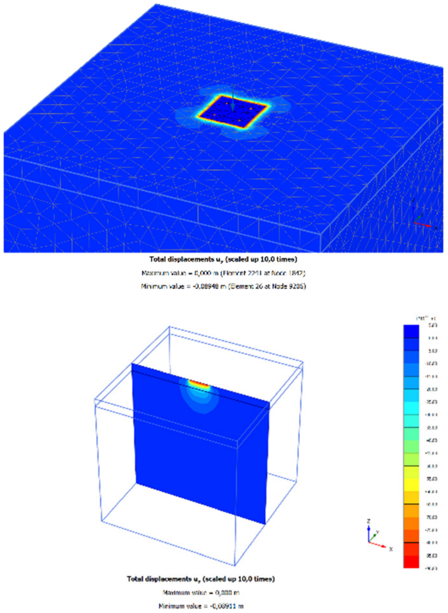

Figure 11 *Total settlements of the model for the SLS phase*

The overall settlements of the 3D model -are 0.089 m (approximately 8.9 cm).

COMPARISON AND CONCLUSION

The comparison between 2D and 3D analyses reveals that the choice of modeling approach must be closely aligned with the nature of the geotechnical problem. For slope stability, where the geometry and loading are uniform along the length of the slope, both 2D and 3D models produced nearly identical values for displacements and global safety factors. In such cases, 2D analysis is sufficient and more efficient, avoiding the complexity and time investment required for 3D modeling. However, in the case of settlement analysis, significant discrepancies were observed—3D modeling yielded almost double the settlement compared to the 2D results. This highlights that when the structure is subject to localized loads and has finite dimensions (as with foundation slabs and piles) the third dimension plays a critical role and cannot be ignored. In conclusion, proper assessment of geometry and loading conditions must precede model selection, ensuring both accuracy and efficiency in the design process.

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