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LIMIT ANALYSIS OF CONCRETE SOLDIER-PILE WALLS IN CLAY: INFLUENCE OF THE HEIGHT OF THE EXCAVATION LEVELS ON VERTICAL STABILITY

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Summary. *In excavations supported by anchored concrete soldier-pile walls, the last stage of the excavation is determinant with regard to vertical stability. In a previous paper the authors applied limit analysis to study the vertical equilibrium of these walls and suggested the possible influence of the height of the last excavation level. In the present paper the influence of this parameter is analysed by using a numerical limit analysis implementation of the Upper Bound Theorem, based on the finite element method. The results enlight the ability of this tool to capture the mechanisms associated with the loss of vertical equilibrium of these structures.*

1 INTRODUCTION

Temporary soldier-pile walls are often used for the support of urban excavations. These walls consist of steel piles inserted in vertical holes drilled at the border of the excavation and timber lagging installed between pile flanges. A permanent structure can be executed by using cast-in-place reinforced concrete, instead of timber lagging. Figure 1 shows the construction sequence of concrete soldier-pile walls.

These structures are usually anchored, and anchors impose significant vertical forces on the vertical piles. Vertical equilibrium of the wall requires (see Figure 2a) that the following equation be verified:

$$W_w + \sum A \sin\beta = N_{pile} + F_l \tag{1}$$

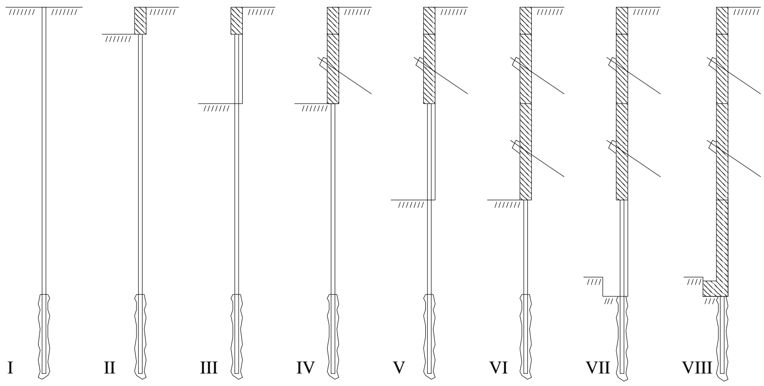

Figure 1: Construction sequence of a concrete soldier-pile wall

where: W_w is the weight of the wall per unit length; $\sum Asin\beta$ is the vertical force applied by the anchors per unit length of the wall; N_{pile} is the reaction mobilized on the soldier-piles per unit length of the wall; F_l is the shear force mobilized at the soil-to-wall interface per unit length of the wall, which can be written as $F_l = pc_aH_w$. In this expression p is the mobilized ratio of the interface resistance, which can assume values between -1 (full downwards mobilization) and $+1$ (full upwards mobilization); c_a is the soil-to-wall resistance (adhesion); H_w is the wall height at each excavation level and, so, the corresponding length of the soil-to-wall interface. The soil is, therefore, assumed to respond in undrained conditions, with undrained resistance c_u.

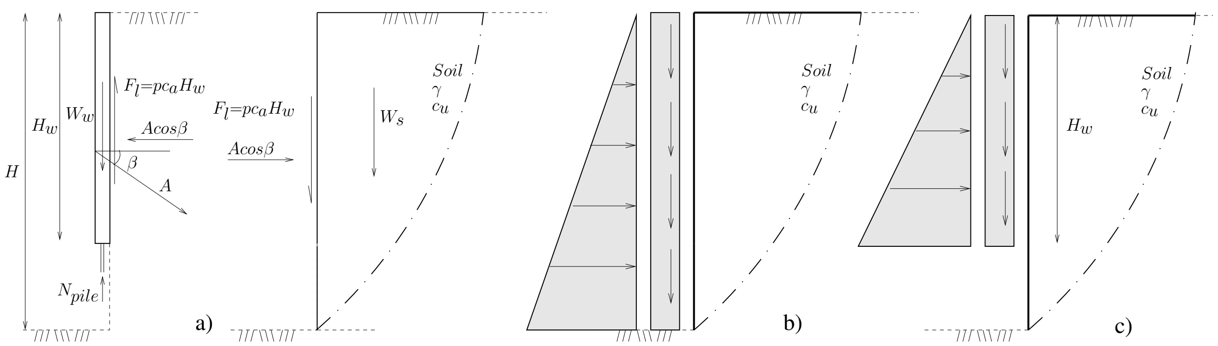

Figure 2: Forces and stresses acting on the wall and soil mass.

The problem of vertical equilibrium is, however, a soil-structure interaction problem, and therefore equilibrium of the soil mass must also be considered (see Figure 2a). This is the problem addressed in this paper.

2 THE PROBLEM OF SOIL STABILITY

The authors studied, in previous papers, the problem of the soil equilibrium using both the stress-strain finite element method and analytical limit analysis upper bound solutions[1], as well as numerical limit analysis[2]. These works have been carried out considering the stress diagrams represented in Figure 2b, which correspond to the final stages of construction of each excavation level (see, for example, stages VI and VIII in Figure 1). However, considering the construction sequence represented in the same figure, stage VII is the critical one. In a general situation, the critical stage is the one corresponding to the last excavation level, before the concrete of that level being cast-in-place. Figure 2c shows the stress distribution to be considered in this work.

The tool used in this work is a numerical implementation of the Upper Bound Theorem of Limit Analysis which optimizes the continuous displacement fields that are automatically generated in order to give accurate upper bound limit loads. Using this numerical finite element model, it is possible to search for combinations of the two stress distributions (normal and tangential to the soil vertical cut) causing imminent collapse of the soil mass represented in Figure 2c. In the situation under study, for each case (H, γ and c_u), the shear stress was fixed and the maximum normal stress was obtained.

3 RESULTS

The results of the horizontal force as a function of the tangential stresses at the soil-to-wall interface are represented in Figure 3, for different values of the stability number, N_S, and H_w/H ratio.

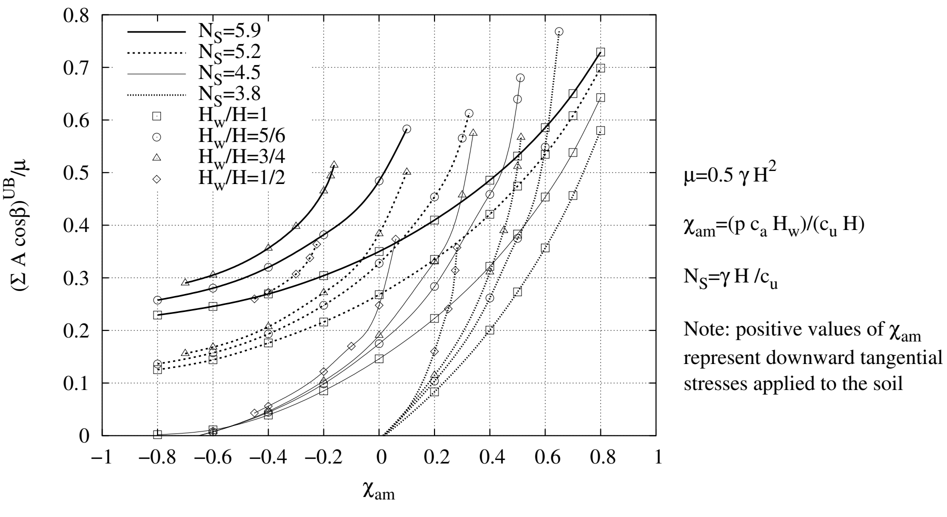

Figure 3: Limit horizontal force *versus* tangential stresses on the soil mass.

The analysis of the figure shows that the stress distributions represented in Figures 2b and 2c lead to significantly distinct relations between $\sum A \cos\beta$ and χ_{am}, particularly for high values of N_S (less resistant soils). The reason for the influence of the stress distribution can be seen in Figure 4, where the deformed meshes show the mechanisms for two values of χ_{am} (-0.2 and +0.3) and for two values of the ratio H_w/H (3/4 and 1). For $\chi_{am} = -0.2$ the mechanisms are alike for both values of H_w/H whereas for $\chi_{am} = 0.3$ significant differences arise. For this last case, the calculation with $H_w/H = 3/4$ reveals a mechanism in which the soil flows behind and underneath the wall due to a more unfavourable distribution of tangential stresses applied by the wall to soil mass.

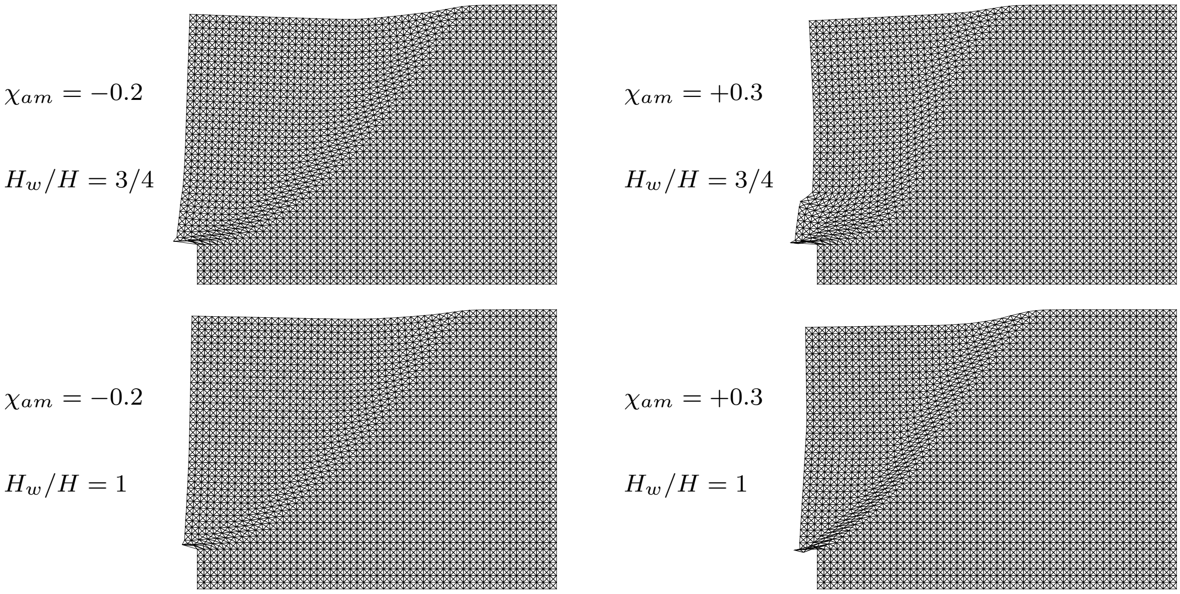

Figure 4: Mechanisms obtained by numerical limit analysis for $N_S = 4.5$.

4 CONCLUSIONS

Numerical limit analysis makes it possible to obtain, without any *a priori* assumptions, the mechanisms involved in soil mass instability. It was applied to the problem of the stability of excavations of clayey soils, in undrained conditions, supported by concrete soldier-pile walls, for different wall heights. The importance of the ratio H_w/H was emphasized, particularly for high values of the stability number. The importance of this ratio is explained by the different mechanisms involved in soil instability.

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