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Numerical study of the Ultimate Pullout Capacity of Vertical Anchor Plate

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Three-dimensional analysis.

Abstract

The dimensioning of a retaining structure consists in determining the geometric and structural elements so that it is stable under the action of the forces applied to it and in particular of the passive and active earth pressure. The stability of these structures is often ensured by anchors placed in the soil. The anchor plates are largely based on passive earth pressure to resist to the ultimate pullout capacity. This study focuses on a numerical study using the software PLAXIS 3D Tunnel, to evaluate the ultimate pullout capacity of vertical square anchors plate embedded in a frictional soil. The soil was considered to be a linearly elastic-perfectly plastic material, obeying Mohr–Coulomb criterion. The variation of the ultimate pullout force was calculated as a function of the variation of the anchor depth. The anchor break-out factors were estimated for a rigid and rough vertical plate, subjected to horizontal loads. The results have been compared with those available in the literature.

1.Introduction

The design of the retaining structures, whatever their type, implies the application of active and passive thrusts theories to the calculations of the loads exerted on the structure by the field. Conventional methods require the determination of classical active and passive thrusts distributions, influenced by different coefficients. These calculation methods, also known at the rupture, are based on simplified behavior schemes assuming that the soil is in limit active or passive thrust.

Anchors embedded in the soil are often used to ensure the stability of these structures. These members, referred to as soil anchors, are generally attached to the structure and embedded at a depth sufficient to resist pullout forces safely.

The anchor plates are largely based on passive earth pressure to resist the pullout loads. The study of the behavior of an isolated anchor plate has been widely discussed by many researchers using experimental, analytical or numerical methods.

Ovesen (1964), conducted tests on a full scale model; these tests have shown that the passive earth pressures against the anchor blocks of limited width, are higher than those provided according to the conventional schemes, and the difference can be quite significant. Ovesen and Stromann (1972) used the failure mechanism proposed by Hansen (1953) to estimate the earth pressures for the case of a continuous shallow plate anchor flushing with the cohesion-less ground surface, termed as the basic case ($H/h = 1$), where h is the height of the plate anchor, H embedment depth, Based on the developed failure mechanism, the ultimate pullout capacity Tu per unit length of a strip anchor was estimated by Ovesen and Stromann (1964, 1972) by the following expression using horizontal force equilibrium: $Tu= Ppx - Pax$,where Ppx and Pax are the horizontal components of the passive and active thrusts, which can be estimated using the earth pressure coefficients reported by Caquot and Kerisel (1949). Neely et al. (1973) performed laboratory tests on plate anchors in dry sand and ultimate resistances of these plates were examined using both limit analysis and the method of stress characteristics. Das and Seeley (1975) conducted several laboratory model tests to determine the ultimate pullout resistance of shallow vertical anchors and suggested a simple semi-empirical relation for the pullout resistance for square and rectangular anchors. The capacity of deeper vertical anchors in medium dense sand was investigated by Akinmusuru (1978) for square, circular and rectangular anchors. On the basis of experimental findings, Dickin and Leung (1983) conducted both centrifuge and conventional chamber tests and reported very thorough investigations on the behaviour of vertical square and rectangular anchors in dense sand. Hoshiya & Mandal (1984) investigated the capacity of square and rectangular anchors in loose sand. Merifield et al. (2006) presented a synthesis of experimental and theoretical research, conducted for the study of anchor plates. Naser (2006) carried out theoretical as well as experimental studies on the ultimate pullout capacity of an anchor block of concrete embedded in sand and observed that, anchor thickness contributed to the pullout capacity through base friction forces. This effect was not significant as compared to the passive resistance.

While there are a variety of experimental results in the literature, very few rigorous numerical analyzes were performed to determine the ultimate capacity of the anchors. Previous numerical studies of anchors have generally used simple analytical approaches such as the limit equilibrium method, and the limit analysis method. Limit analysis technique of the upper and lower bound limits were used by Murray and Geddes (1987, 1989), Basudhar and Singh (1994) and Smith (1998) to estimate the capacity of vertical anchor plates. More rigorous studies have been conducted by Rowe and Davis (1982), Tagaya et al. (1983, 1988), and Sakai and Tanaka (1998), using the finite element technique.

However, important recent studies conducted by several researchers have made it possible to understand and deal the problem of soil anchors, for example, Hanna A et al (2011), Kame GS et al (2012), Das BM and Shukla SK (2013), Wang D and Merifield RS and Gaudin C (2013), Mabrouki A and Mellas M (2014), Choudhary AK and Dash SK (2017).

Two-dimensional numerical analysis in plane or axisymmetric deformation does not allow to study faithfully the behavior of a square anchor plate with the exception of a few approaches in axisymmetric by simplification of the square shape by an equivalent circular shape. Such justification calculations were carried out by the Division of Soil Mechanics, Rocks and engineering geology of the LCPC in the framework of the exploitation of experimental studies on shallow foundations (Mestat et berthelon. 2001). Currently, three-dimensional numerical calculations in geotechnical engineering help to better understand the overall behavior of structures, and thus help engineers to identify the most critical elements of design. So, in this paper, a three-dimensional numerical study was chosen using the PlAXIS 3D Tunnel finite element code in order to treat the problem properly and lead to more convincing results. The results obtained are the subject of a comparison with the formulations available in the literature.

2. Numerical modeling

In this study, a three-dimensional numerical model developed using the finite element method in PlAXIS software, the studied problem considers an isolated anchor plate, defined by its height h and its width b (h = b = 1 m), and subjected to a horizontal Pullout force Qu (Fig.1). The anchor plate is assumed to be square, rigid and rough, Embedded vertically in a purely Cohesion-less and homogeneous soil at a depth H; depending on the location of the anchor plate near the ground surface, five cases are considered; H/h = 1, 2, 3,4et 5.

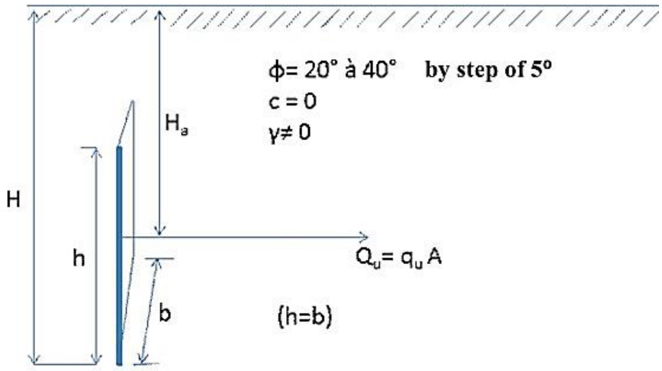

Figure 1. Model geometry

In all cases, due to the symmetry of the problem, only half of the model was considered. The numerical model has 4th order 15-node triangular finite elements, which provide finest distribution of stress–strain in soil mass. Several meshes were considered with a half-width of the plate (b / 2 = 0.5 m), a local refinement of the mesh was carried out in the suspected zones with strong gradients of the stresses, in the vicinity of the anchor block. The dimensions of the massif adopted are sufficient for the mechanism of rupture does not intercept the borders. Many tests were carried out to examine the influence of the size of the model on the anchor limit force Qu. An example of the adopted mesh with triangular finite elements at 15 -node, medium, refined in the vicinity of the plate, comprising 2500 elements, is illustrated in the figure (Figure 2).

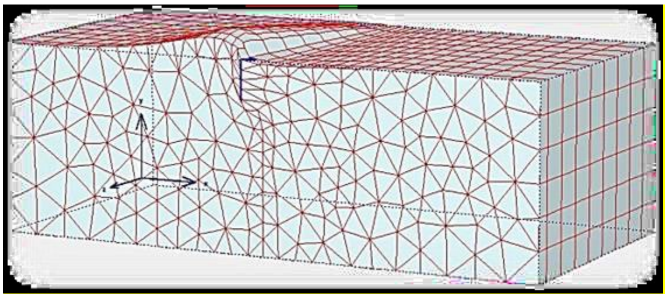

Figure 2. Mesh used for the case of an anchor plate limited by a horizontal free surface (H/h = 1).

Boundary conditions are taken into account by blocking horizontal and vertical displacements for the lower bound, and blocking horizontal displacements for the model's symmetry planes and peripheral planes.

In this study the behavior of the soil is governed by an elastic-perfectly plastic law and the Mohr-Coulomb criterion has been adopted; this model is characterized by a modulus of elasticity E = 30000 kN / m2, Poisson's ratio υ = 0.3, a density γ = 18 kN / m3, a zero cohesion; the angle of friction φ has been varied between 20 ° and 40 ° with an increment of 5 °; for the dilation angle, we used an associated flow law (ψ =φ).

The rigid non-deformable anchor plate was modeled by horizontally imposed displacements and blocked vertically at the nodes. During the calculation process, the imposed displacements gradually increase incrementally until the stabilization of the resulting force which represents the ultimate pullout load Qu of the anchor plate, break-out factor Nγ can be calculated from of the following formula:

$$q_u = \gamma H N_Y \qquad (1)$$

With: qu= breaking stress; Nγ= break-out factor; H= embedment depth; γ= density of the soil.

Table 1. Soil mechanical properties

Soil unit weight	γ (kN/m³)	18
Young's modulus	E (kN/m²)	30000
Poisson's ratio	ν	0,3
Cohesion	c (kN/m²)	0
Internal frictional angle	φ(°)	de 20°à 40° by step of 5°
Dilation angle	ψ(°)	(ψ=φ)

3. Results and discussion

3.1 Load-displacement curve

Figure 3 shows the evolution of the reaction force as a function of the displacement imposed for the anchor plate in the case of the internal friction angle of the soil φ = 20 ° with H / h = 1, 2, 3,4 et 5 et (ψ = φ). For each depth studied, the reaction force increases with the increase of the imposed displacement, until stabilization at a certain value which represents the ultimate pullout force. The latter increases with the increase of the embedment depth.

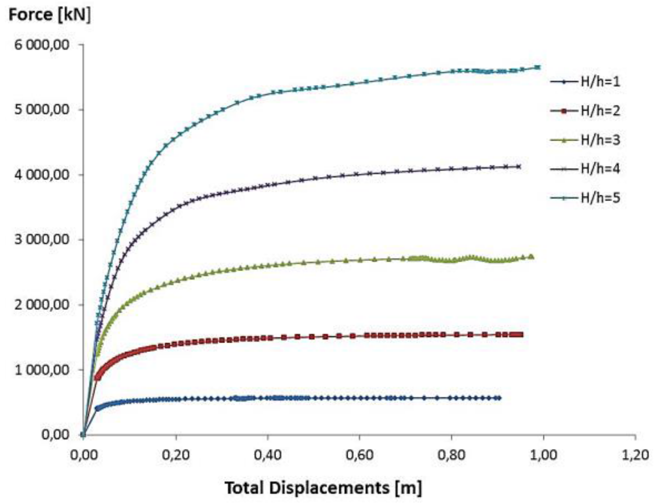

Figure 3. The ultimate pullout capacity for the anchor plate

3.2 Break-out factor Nγ

Figure 4 compares the Nγ values obtained by this study with those found by Merifield et al. (2006) and Meyerhof (1973); the results presented in this figure were obtained by considering an associated soil. It is noted that the results of Nγ given by Merifield et al. (2006) are obtained by applying the lower and upper bounds of the three-dimensional limit analysis using the finite element method. In general, it may be noted that the results of the present study are in very good agreement with those obtained by the upper bound procedure based on finite elements and those obtained by the semi-empirical theory presented by Meyerhof (1973). The values in this study are slightly underestimating Nγ factor relative to the results of Merifield et al. (2006). Also, the analysis of the results presented in Figure 4 allows to notice an almost linear variation of Nγ with the depth.

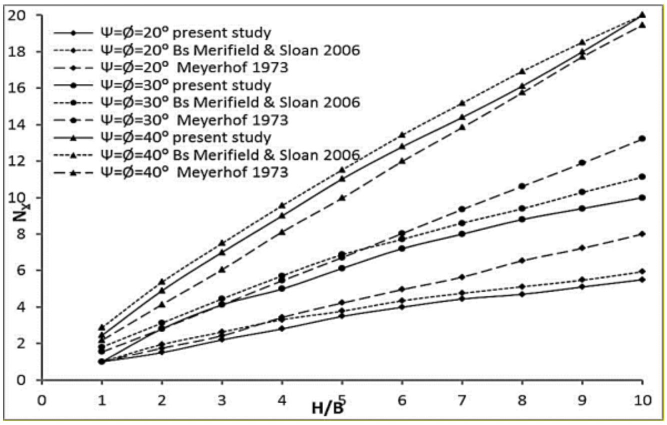

Figure 4. Comparison of Nγ obtained by the present study with the results of the upper bound of Merifield and Sloan (2006) and the semi-empirical theory of Meyerhof (1973).

The effect of soil dilatation on the anchor capacity has been studied, in order to demonstrate the influence of soil non-associativity on the Nɣ factor, in Figure 5 are presented the results of Rowe (1978), determined using the finite element displacement technique with a non-associated flow rule (ψ= 0), and the results determined by previously performed numerical calculations with an associated flow rule (ψ = φ). It is observed that the Break-out factors of the current study are superior to those obtained by Rowe due to the effect of soil dilation.

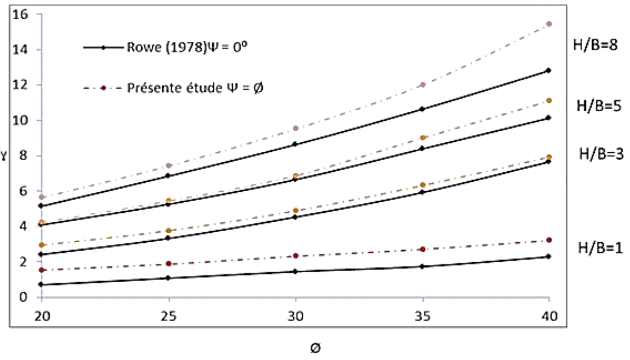

Figure 5. Comparison of Nγ obtained by the present study with the results of Rowe (1978)

A comparison of the Nɣ values obtained in this study with those found by experimental tests previously carried out by Neely et al. (1973), and Akinmusuru (1978) are shown in Figure 6. The results shown in Figure 6 indicate that the numerical computation is successful, with only very small error limits observed. The Calculated estimates are in excellent agreement with the results of Neely et al. (1973). It was found that the error limits increased with increasing friction angle.

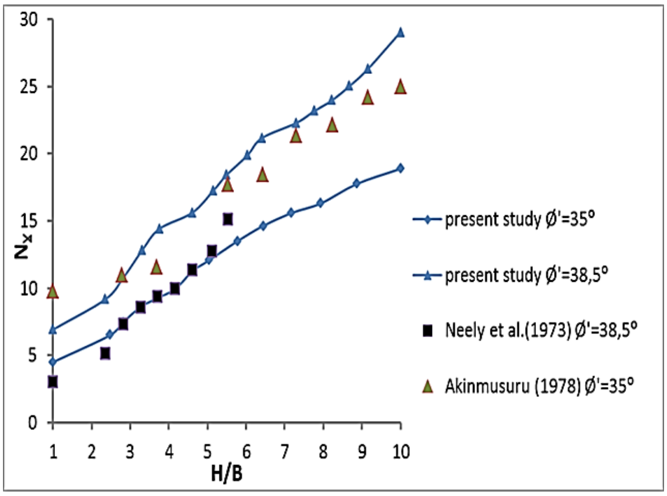

Figure 6. Comparison of Break-out factor from the current study with the experimental results of the other authors

3.3 Mechanism of rupture

Failure mechanisms are represented by the finite element displacement contours in Figure 7, where different values of φ were used in the displacement field presentation for various H/h ratio values. Examination of these figures shows the influence of the internal friction angle φ on the total displacement of the anchor plate. It has been found that the increase in lateral shear increases with an increase in the angle of friction at a given anchor depth.

4. Conclusions and perspectives

The anchor limit forces for the plates in square configuration were determined by the PlAXIS 3D Tunnel code in this study, in order to determine the Nγ Break-out factors in the case of H / B ratios of less than 10 and internal friction of the soil less than 40 °. The square, rough and rigid anchor plates were installed vertically in dense sand and subjected to a horizontal pullout force. Soil behavior was characterized by Mohr Coulomb's criterion with a non-associated flow law (ψ= φ).

The numerical experiments made the following conclusions:

The numerical simulation with the Plaxis 3D Tunnel computation code gave satisfactory results in comparison with those given by the Merifield et al. (2006) and those obtained by the semi-empirical theory presented by Meyerhof (1973).

On the other hand, the comparison of the Nγ results, determined using Rowe's (1978) finite element displacement technique with a non-associated flow rule (ψ = 0), with the numerical calculations presented. in this study in the case of an associated soil (ψ = φ), have confirmed the influence of the non-associativity of the soil which underestimates the Nγ factor. It is observed that the Break-out factors of the current study are superior to those obtained by Rowe due to the effect of soil dilation.

In general, it has been found that the displacement field and the failure mechanism are influenced by the internal friction angle of the soil φ. An increase in lateral shear is observed with an increase in the angle of friction at a given depth of anchor.

The results obtained from a selection of existing experimental studies were compared with the numerical predictions obtained in the current study. The comparison shows an encouraging agreement.

The present study allowed to understand the three-dimensional behavior of a vertical, rigid, rough and isolated anchor plate. Several perspectives of different nature can be envisaged in this paper, such as the study of the interference of a group of vertical anchor plates; also, the study of the limit load of inclined anchor plates.

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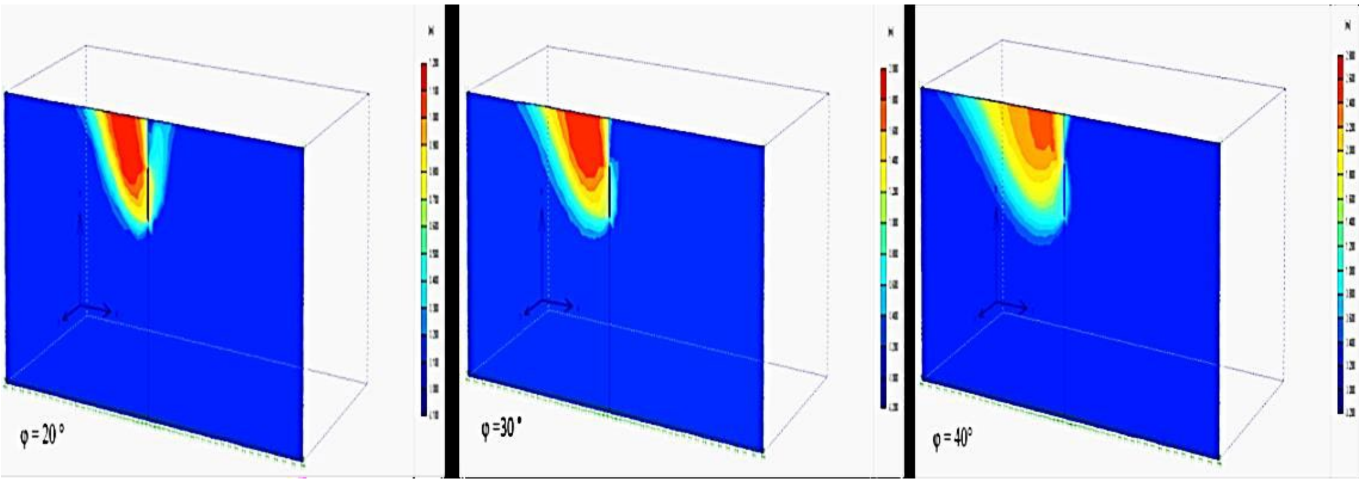

Figure 7. Total displacements for φ = 20°, 30°, 40° and H/h= 2

Declaration of Conflict of Interests

The author(s) declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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