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Discussions on the Computation of Buoyancy for Underground Structure inside Soil

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Abstract: ***With the development of underground space and the scare of land resources, the problem of anti-floating for underground structure received more and more attention. The computation of buoyancy is the key during the design of anti-floating for underground structures. In this paper, a simplified model was established to demonstrate the transfer of water pressure transfer inside soil exists reduction in time scale and space scale, and the law of water pressure transfer and the relationship between water pressure transfer and buoyancy were presented. Ultimately, a formula was proposed to compute the safety factor of anti-floating of underground structures, which may provide a reference for anti-floating of underground structures.***

Keywords: Anti-floating; buoyancy; water pressure; reduction; safety factor of anti-floating.

1 Introduction

With the development of underground space and the scare of land resources, high-rise and super high-rise buildings are adopted frequently, the problem of anti-floating for underground structure received more and more attention [1-3].No matter what kind of anti-floating measure of dealing with the underground water are adopted, the most important part of ant-floating design is computation of buoyancy for underground structure inside soil. However, relevant specifications and manuals involving anti-floating design have not got uniform understanding theoretically . Many scholars also have great differences on this issue, Li et al [4-6]expounded that there is no reduction in the buoyancy of groundwater in both sandy soil and cohesive soil from the perspective of the principle of effective stress, while Fang et al [7] proved the reduction of groundwater buoyancy through experiments and theoretical derivation. In practical engineering, the design of anti-floating for underground structures is mostly based on monitoring data and existing engineering cases, which is too empirical. This paper analyzes the key to the controversy of the buoyancy computation of underground structures, expounds the law of water pressure transmission and its essence with the anti buoyancy computation of underground structures from a micro perspective, and points out that there is a reduction in the water pressure transmission of soil on both time and space scales. Through classical examples, the computation formula of the anti buoyancy stability safety factor of underground structures in soil is put forward, in order to provide reference for the anti-floating design of underground structures.

2 The relationship between water pressure transfer and buoyancy from the micro perspective

The transmission of water pressure in soil is very complex, and the computation of buoyancy is closely related to the transmission of water pressure[8].Assuming that the soil particles are ideal spherical shape, any two soil particles in the soil were taken as the analysis object (as shown in Figure 1). Generally, there are three forms of water around the soil particles: free water, weak bound water and strong bound water, and different forms of water in soil have different degrees of difficulty in transferring water pressure: strong bound water > weak bound water > free water.The transmission of water pressure is realized through the water film between particles, that is, the water film between particles becomes the binding resistance of water pressure transmission. Similarly, this binding resistance can be divided into three forms: free water as the main binding resistance, weak bound water as the main binding resistance and strong bound water as the main binding resistance (as shown in Figure 1). The process from 1 (a) to 1 (c) can be regarded as the process of soil compaction, and the opposite is disturbance.

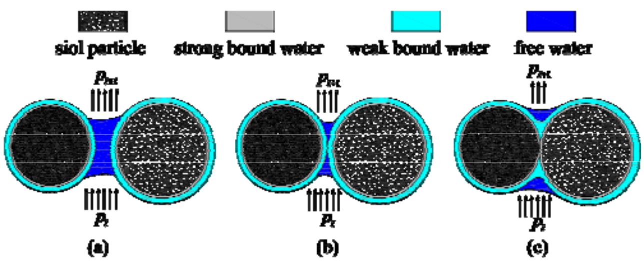

Fig.1 Diagrammatic sketch for transfer of water press between soil particles during soil compressing.

Water pressure will be reduced from p_i to p_{i+1} when overcoming the transmission of binding force during transmission as shown in equation (1).

$$p_{i+1} = \xi_i p_i \tag{1}$$

Where, ξ_i is the reduction coefficient of water pressure, which is related to the type, viscosity and thickness of water film.

Formula (1) represents the reduction of water pressure after passing through the water film between any two soil particles. For the complete soil, the transmission relationship of water pressure can be expressed by formula (2).

$$p_n = p_0 \prod_1^n \xi_i = f(x) \tag{2}$$

Where formula (2) indicates that the remaining water pressure p_n after the reduction of initial water pressure p_0 through complex transmission path is (as shown in Figure 2), while the practical transmission path of water pressure is very complex and will not be analyzed in detail in this article. Experiments show that the transmission of water pressure takes time[9-10], considering the time effect of water pressure transmission, formula (6) can be modified as formula (3)：

$$p_n = p_0 f(x) g(t) \tag{3}$$

Formula (3) can be regarded as the reduction of water pressure transmission on time and space scales. For pure sandy soil, $g(t)=1$, $f(x)=1$. For pure cohesive soil, $g(t)=0$, $f(x)=0$, but this soil is almost close to impermeable concrete, which does not exist in reality. For ordinary cohesive soil, $0<g(t)<1$， $0<g(t)<1$.

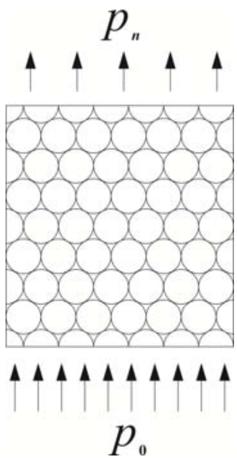

Fig.2 Diagrammatic sketch for transfer of water press inside soil

The buoyancy of underground structures can be calculated by formula (4)：

$$F = p_0 - p_n = p_0 - p_0 f(x) g(t) \tag{4}$$

Assuming $1 - f(x)g(t) = \lambda$ in formula (4), the computation formula of buoyancy can be further simplified as formula (5).

$$F = \lambda p_0 \tag{5}$$

Of course, the above formulas can not fully reveal the transmission law of water pressure in soil temporarily, and a more detailed expression needs to be combined with further experimental research.

3 The computation example of buoyancy of underground structure inside various soil

As shown in Figure 3, the self weight of a reinforced concrete underground structure is G and the top dimension is L×B, The thickness of the overlying soil is h_2, the buried depth of groundwater is h_w, and the natural and saturated gravity of the soil are γ and γ_{sat} respectively. Ignoring the friction between the side wall of the underground structure and the soil, what is the the safety factor of anti-floating the underground structure?

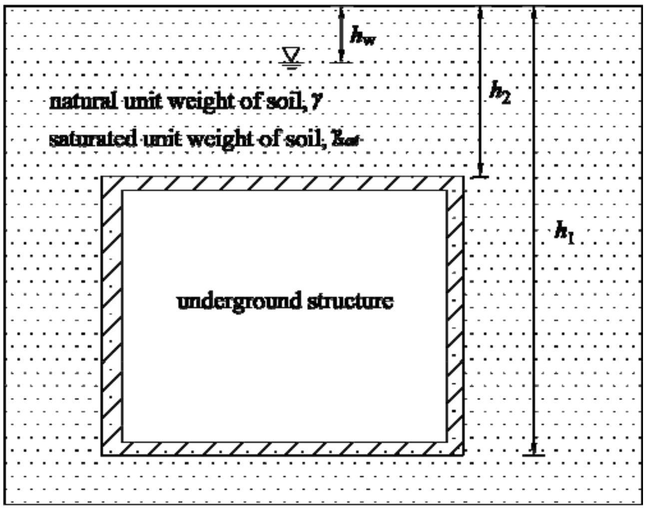

Fig.3 Diagrammatic sketch for the computation of underground structure

The water pressure on the top and bottom of the underground structure is shown in formula (6) and (7):

$$p_1 = \gamma_w (h_1 - h_w) f(x_1) g(t_1) \quad (6)$$

$$p_2 = \gamma_w (h_2 - h_w) f(x_2) g(t_2) \quad (7)$$

The fill weight acting on the top of the underground structure is shown in formula (8).

$$p_3 = \gamma h_w + \gamma_{sat} h_w (h_2 - h_w) - \gamma_w (h_2 - h_w) f(x_2) g(t_2) \quad (8)$$

The safety factor of anti-floating of underground structure can be calculated by formula (9)

$$K = \frac{p_3 + G}{p_1 - p_2} = \frac{\gamma h_w + \gamma_{sat}(h_2 - h_w) - \gamma_w (h_2 - h_w) f(x_2) g(t_2) + G}{\gamma_w (h_1 - h_w) f(x_1) g(t_1) - \gamma_w (h_2 - h_w) f(x_2) g(t_2)} \quad (9)$$

For pure sandy soil, $g(t) = 1$, $f(x) = 1$,The safety factor of anti-floating of underground structure can be simplified as formula (10).

$$K = \frac{\gamma h_w + \gamma'(h_2 - h_w) + G}{\gamma_w h_1 - \gamma_w h_2} = \frac{\gamma h_w + \gamma'(h_2 - h_w) + G}{\gamma_w \Delta h} \quad (10)$$

4 Conclusion

The anti-floating computation of underground structure is closely related to the nature of soil, the stage of soil layer and the type of soil water. At the micro level, the transmission of water pressure has been reduced on both time and space. For sandy soil, almost all water pressure can be transmitted, and the reduction can not be considered in buoyancy computation. For cohesive soil, the computation of buoyancy needs to be reduced according to the model test results and engineering experience. Based on the micro mechanism of water pressure transmission and the essence of buoyancy of underground structure, this paper puts forward the reduction law of time scale and space scale of water pressure transmission in soil, and puts forward the computation formula of anti floating stability safety factor of underground structure in soil through classical computation examples.

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