Tạp chí KH&CN- Trường Đại học Bình Dương, Vol.5 № 1/2022

INFLUENTIAL FACTORS AFFECTING THE DEPTH OF EXCAVATED TRENCH IN UNSATURATED SOILS DUE TO NONLINEAR SUCTION DISTRIBUTION

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Received: January 13, 2022 Revised: March 10, 2022 Accepted: March 19, 2022

ABSTRACT.

Depth of an excavated trench plays a vital role on stability as well as economic efficency of an open trench. As design and analysis excavation construction method, selection of an appropriate excavated depth value of a trench without support structures is necessary. In practice, excavated trench is usually located above ground water table or under unsaturated soil condition. Therefore, the depth of unsupported trench is significantly affected by unsaturated soil properties, especially suction distribution and physical properties of soil as well. To date, there have been a few theories and research works reported on the method of determining a suitable depth of a trench under unsaturated condition. However, previous works tend to assume that the distribution of soil suction is either constant or linear with depth; as a result of this assumption, the designed results are often overestimated compared to practical results. In this paper, the effect of nonlinear distribution of suction was taken into account to propose an equation to estimate the depth of an excavated trench without support structures. Eventually, an example of numerical computation was executed to figure out the factors that affect the depth of excavated trend considering non linear suction distribution of unsaturated soils.

Keyword:

1. Introduction

Previous researches indicated that critical depth, H, or ratio of depth and width of open trench, L, is one of the essential considerations of design used to study and analyze the stability of unsupported trenches or excavations. The L/H ratio must be met both the stability of underground structure requirement and economic effectiveness. The L/H ratio controls the angle of the open trench, hence amount of excavation work required. The less the value of β (as shown in the Fig. 1) is, the higher stability of the open trench; however, the larger the amount of excavation work need to be done. Economically side speaking, once the value of β equals to 90° the amount of excavation work required is lowest, hence the highest of effectiveness of economic. In spite of this, the stability of the open trench must be taken into account. It is widely observed that under this condition $\beta = 90°$, some external supporting structures (known as the temporary structure) need to be applied such as earth anchor, retaining wall, struts, sheet pile. As a result of this requirement, some shortcoming might be seen as follows (Ou, C.Y., 2014; Puller, M., 2015):

- Due to the existence of the temporary structures, the construction

DOI : https://doi.org/10.56097/binhduonguniversityjournalofscienceandtechnology.vi1.18

area of underground construction is reduced.

- It is costly since the temporary structures needed.

- Progress of construction work is significantly affected, even much longer as compared to that in case of without using temporary structures.

In addition, excavated trench is usually positioned above ground water table or under unsaturated soil condition. Earlier reseachers regularly assume that the soil suction distribution is constant or linear with depth (Vanapalli, S.K., 2012., Whenham, V., 2007); as a result of this assumption, the designed results are often overestimated compared to practice. So, this paper aims to build up an equation to estimate the depth of open excavated trench considering the nonlinear distribution of soil suction, subsequently, figuring out the main factors that affect the depth of excavated trench without support structures.**Required depth of an open trench**

In order to find out an applicable value of the depth of an open trench, a typical cross section of trench is made as shown in **Fig. 1**.

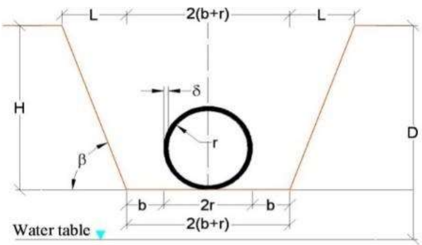

Fig. 1*. A typical cross section of an open trench*

According to Kartozia B.A., (1983), the required depth, H must be fulfilled the following conditions:

$$H \geq (2 \div 5)2r = (4 \div 10)r \qquad (1)$$

and

$$D > H + m \qquad (2)$$

Where: m is the thickness of backfill soil layer which used to resist the water penetration under high pressure, this parameter can be defined as below Terzaghi K., (1941):

$$m \geq \frac{h}{(\frac{\gamma_s}{\gamma_w} - 1)} \qquad (3)$$

Where γ_s, γ_w are the density of soil, and water respectively (kN/m^3); h is the height of pressurized water once groundwater seepage into the open trench.

2. Matric suction in unsaturated soil

One of the most important characteristics of unsaturated soil is the negative pore water pressure. The pore water pressure due to capillarity is negative (suction), it is defined as a function of the size of the soil pores and the water content (**Fig. 2**), (Budhu, 2000).

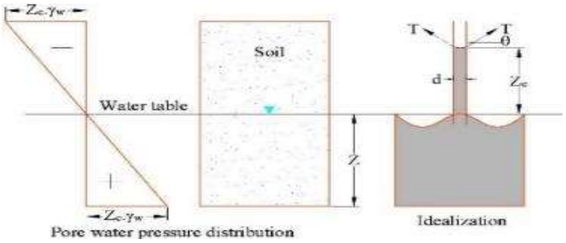

Fig. 2*. Simulation of capillary in soil*

At the groundwater level, the pore water pressure is zero and decreases (becomes negative) as the capillary zone goes up. Because of presence of the negative pore water pressure, the effective stress increases. To specify, for the capillary zone, zc, the pore water pressure at the top is -zcγw, hence the effective stress (Fredlund, 2014; Fredlund et al., 2012; Fredlund et al., 1996) stated that profile of matric suction in a horizontally layered unsaturated soil generally depends on several factors; especially the soil properties as given by soil water characteristic curve and the soil permeability, environmental factors including infiltration due to precipitation or evaporation rates and boundary drainage conditions including the location of groundwater level. The matric suction profile will come to equilibrium at a hydrostatic condition when there is zero net flux from the ground surface. If moisture content is extracted from the ground surface such as evaporation, the matric suction profile will be drawn to the left (matric suction increases). If moisture enters at the groundwater surface such as infiltration, the matric suction profile will be drawn to the right (matric suction reduces). Under steady state, the water flux in and out of the soil reaches the balance. If the magnitude of water flux is the same as the hydraulic conductivity of the saturated soil, the magnitude of the pore-water pressure is constant (Fig. 3).

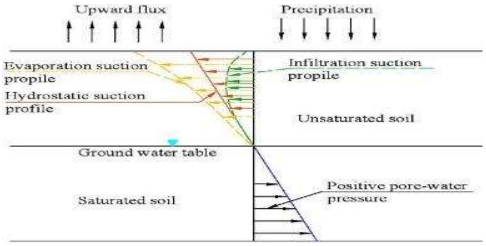

***Fig. 3**. Matric suction profile in horizontally layered unsaturated soil profiles under various surface flux boundary condition (Fredlund, 2014; Fredlund et al., 1996)*

From the distribution of matric suction, it's found that the matric suction profile varies with depth and linearly reduced from surface to the water table; however, once the boundary drainage conditions change is due to either upward flux or precipitation, the distribution of matric suction is not linearly. Therefore, in this paper the change in the distribution of matric suction is assumed as a function of the third order polynomial and expressed as below:

$$F_{hd}(y) = a + by + cy^2 + dy^3 \qquad (4)$$

Where: y is the considered depth of open trench; F_{hd} is the function of matric suction varies with depth. The equation (4) must be met the following conditions:

$$y = 0 \rightarrow F_{hd}(y) = max = k\gamma_n gD$$

$$y = D \rightarrow F_{hd}(y) = 0$$

By considering and comparing with the practical condition, the Eq (4) can be rewritten as:

$$F_{hd}(y) = \frac{A}{D}(D^2 - 2y^2 + y^3/D) \qquad (5)$$

or:

$$F_{hd}(y) = AD(1 - y^3/D^3) \qquad (6)$$

Where $A = k\gamma_n g$, k is the pore water pressure coefficient, which varies with the slope of hydrostatic pressure (or hydrostatic suction profile); *g* is specific gravity. Taking a look into the Eq (5, 6), the magnitude of matric suction is decrease from a value of $AD = kD\gamma_n g$ (at $y = 0$) to zero (at $y = D$). The istribution of matric suction is showed in the **Fig. 4**.

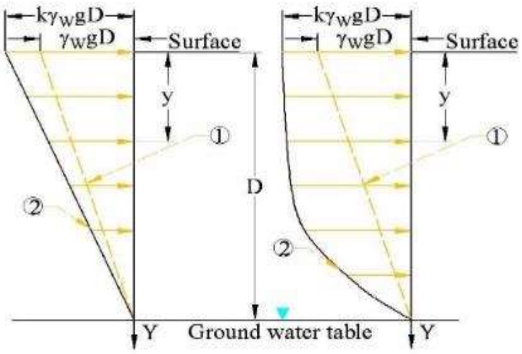

***Fig. 4**. The distribution of matric suction with depth. (1) represent the surface of hydrostatic suction; (2) the distribution line of matric suction*

3. Determination of depth of open trench without supporting structure

3.1. Earth pressure

The horizontal pressures act to the wall of open trench is caused by the active earth pressure, pa, which can be determined as follow (Bang, 1985; Terzaghi, 1941; Terzaghi et al., 1996; Wang, 2000):

$$P_a = (\sigma_n - u_a) = (\sigma_d - u_a)cotg^2\left(\frac{\pi}{4}-\frac{\varphi'}{2}\right) - 2C.cotg\left(\frac{\pi}{4}-\frac{\varphi'}{2}\right) \quad (7)$$

Where:

$$\sigma_d = \gamma_d.g.y \quad (8)$$

C is the total cohesion stress which consists of two components, one is the effective cohesion, *C*’; the other is suction force: $(u_a - u_w)tg\ \ _b$. In other words:

$$C = C' + (u_a - u_w)tg\varphi_b \quad (9)$$

Combination of Eq (9) and (7):

$$P_a = (\sigma_n - u_a) = (\sigma_d - u_a)cotg^2\left(\frac{\pi}{4}-\frac{\varphi'}{2}\right) - 2[C' + (u_a - u_w)tg\varphi_b]cot \quad \frac{\pi}{4}-\frac{\varphi'}{2}\Big) - 2(u_a - u_w)tg\varphi_b cotg\left(\frac{\pi}{4}-\frac{\varphi'}{2}\right) \quad (10)$$

Substitute Eq (5) into Eq (10):

$$P_a = (\sigma_n - u_a) = (\sigma_d - u_a)cotg^2\left(\frac{\pi}{4} - \frac{\varphi'}{2}\right) - 2[C' + (u_a - u_w)tg\varphi_b]cot \quad \frac{\pi}{4} - \frac{\varphi'}{2}\Big) - 2tg\varphi_b cot \quad \frac{\pi}{4} - \frac{\varphi'}{2}\Big).\frac{A}{D}(D^2 - 2y^2 + y^3/D) \tag{11}$$

Substitute Eq (8) into Eq (11):

$$P_a = (\sigma_n - u_a) = (\gamma_d.g.y - u_a)cotg^2\left(\frac{\pi}{4} - \frac{\varphi'}{2}\right) - 2C'cotg\left(\frac{\pi}{4} - \frac{\varphi'}{2}\right) - 2tg\varphi_b cotg\left(\frac{\pi}{4} - \frac{\varphi'}{2}\right).\frac{A}{D}(D^2 - 2y^2 + y^3/D) \tag{12}$$

The total magnitude of active earth pressure acts to the retaining wall with its height of H_t, P_a, can be defined as:

$$P_A = \int_0^{H_t} P_a dy \tag{13}$$

3.2. Determine the magnitude of depth of open trench

The distribution of active earth pressure can be divided into two regions, one is tensile region, the other one is compressive region. Two these regions are separated at a depth of y_k. In the tensile region (from the surface to depth of y_k), the active earth pressure is negative, which causes soil mass behinds retaining wall tends to move away from the retaining wall. The magnitude of y_k may be estimated by combination Eq (10) and Eq (5, 6), together with a condition of $P_a = 0$ and $u_a = 0$:

$$\sigma_d cotg^2\left(\frac{\pi}{4} - \frac{\varphi'}{2}\right) - 2C'cotg\left(\frac{\pi}{4} - \frac{\varphi'}{2}\right) - 2tg\varphi_b cotg\left(\frac{\pi}{4} - \frac{\varphi'}{2}\right).\frac{A}{D}(D^2 - 2y^2 + y^3/D) \tag{14}$$

After working out the Eq (14), the value of y_k can be found.

If total active earth pressure P_a acts to the retaining wall is completely dissipated, the corresponding depth under that condition will be the one that can be applied without supporting structure. In other words, the magnitude of depth of the open trench, y_{kc}, can be determined by solving the following equation:

$$P_A = \int_0^y P_a dy = 0 \qquad (15)$$

By substituting Eq (11) into Eq (15), and working out the Eq (15) with y is the variable, the y_{kc} can be derived, and its value is a function of:

$$y_{kc} = f(\varphi', \varphi_b, u_a, \sigma_d, D, A) \qquad (16)$$

4. Numerical caculation results and Discussion

4.1. Numerical Calculation

Numerical calculation is carried out using concept of equation (16), in which the input parameters of soil sample such as physical and mechanical properties of the studied soil is shown in the **table 1**. The study soil sample was collected in a construction site located in the Southeast of Vietnam.

Table 1. *Soil parameters used in this paper*

Description	Symbol	Unit	Value
Effective cohesion	γ	kN/m^3	18
Effective friction angle	C'	kPa	50
Effective friction angle associated with matric suction	φ'	Degree	22
Pore-water pressure coefficient	φ_b	Degree	14
Other parameters	k	-	15
Pore air pressure	u_a	kPa	0

4.2. Effect of level of ground water table

By changing the level of groundwater table, *D*, the relationship between depth of the open trench without supporting structure and *D*, can be found (**Table 2**), and (**Fig 5**).

Table 2. *Relationship between kkc and level of ground water table*

Depth of ground water table, *D*	7	8	10	13	15
k_{kc}	4.4	5.0	5.8	7.2	7.3

4.3. Effect of effective friction angle

Table 3. *Relationship between kkc and effective friction angle (**Fig 6**)*

Effective friction angle, φ'	10	18	26	30	35
k_{kc}	4.85	4.34	3.87	3.57	3.32

4.4. Effect of effective cohesion

Table 4. *Relationship between kkc and effective cohesion (**Fig** 7).*

Effective friction angle, *C'*	kPa	20	50	60	70	85
k_{kc}	m	3.7	4.2	4.3	4.4	4.6

4.5. Effect of pore water pressure coefficient

Table 5. *Relationship between kkc and pore-water pressure coefficient (**Fig 8**).*

Description	Values, m				
Pore-water press. coef., *k*	1.0	1.2	1.5	1.7	2.0
k_{kc}	3.2	3.7	4.2	4.5	5.0

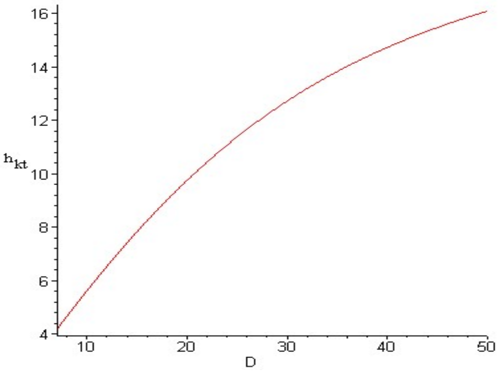

Fig. 5. *Relationship between k_{kc} and level of groundwater table.*

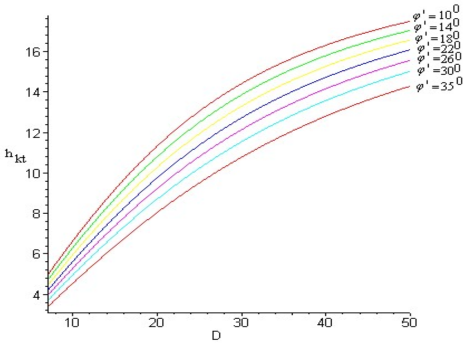

Fig. 6. *Relationship between k_{kc} and effectivefriction angle.*

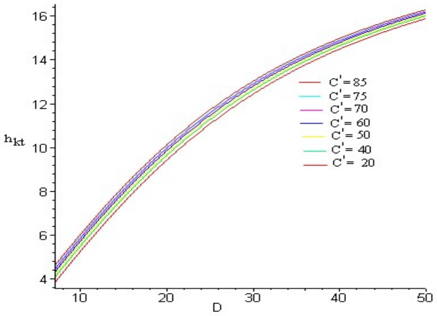

Fig. *7. Relationship between k_{kc} and effective cohesion.*

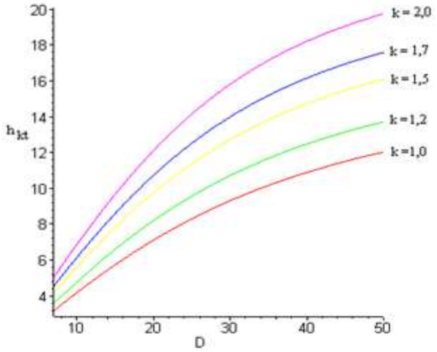

Fig. 8. *Relationship between k_{kc} and pore-water pressure coefficient.*

4.6. Discussions

Numerical calculation results in the section 5 show that:

-The magnitude of kkc is nonlinearly increased with the level of groundwater table; however, once the level of groundwater reaches the certain value, the value of kkc almost constant and tends to reach the critical value.

-Under the same conditions, the unsupported depth of an open trench, kkc are as follows:

+ The value of kkc decreases with an increase of effective friction angle.

+ The value of kkc does not significantly increase as the effective cohesion increases.

+ The value of kkc is notably increased as the pore-water pressure coefficient increases.

5. Conclusion

The paper aim at poiting out the factors that affect the unsupported depth of open trenches considering the nonlinear distribution of soi suction. Numerical calculation result indicates that unsupported depth of trench is notably affected by the unsaturated soil properties. Additionally, to achieve optimum design of open trench, the geotechnical designers should take soil suction into account, in which the distribution of soil suction should be considered as nonlinearly distributed.

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CÁC YẾU TỐ ẢNH HƯỞNG ẢNH HƯỞNG ĐẾN VIỆC GÂY TỬ VONG CỦA TRUYỀN LÃO HẤP DẪN TRONG ĐẤT KHÔNG BỀN VỮNG DO PHÂN BỐ HẤP THỤ KHÔNG TUYỆT ĐỐI

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Ngày nhận bài: 13/01/2022 Biên tập xong: 10/3/2022 Duyệt đăng: 19/3/2022

TÓM TẮT

Độ sâu của rãnh đào đóng một vai trò quan trọng đối với sự ổn định cũng như hiệu quả kinh tế của rãnh mở. Khi thiết kế và phân tích phương pháp thi công đào, việc lựa chọn giá trị độ sâu đào thích hợp của hào không có kết cấu hỗ trợ là cần thiết. Trong thực tế, rãnh đào thường nằm trên mực nước ngầm hoặc trong điều kiện đất không bão hòa. Do đó, độ sâu của rãnh không được hỗ trợ bị ảnh hưởng đáng kể bởi các đặc tính của đất không bão hòa, đặc biệt là sự phân bố lực hút và các đặc tính vật lý của đất. Cho đến nay, đã có một số lý thuyết và công trình nghiên cứu được báo cáo về phương pháp xác định độ sâu thích hợp của rãnh trong điều kiện không bão hòa. Tuy nhiên, các công trình trước đây có xu hướng cho rằng sự phân bố của lực hút đất là không đổi hoặc tuyến tính với độ sâu; kết quả của giả định này, kết quả thiết kế thường được đánh giá quá cao so với kết quả thực tế. Trong bài báo này, ảnh hưởng của phân bố phi tuyến của lực hút đã được tính đến để đề xuất một phương trình ước tính độ sâu của rãnh đào mà không có kết cấu hỗ trợ. Cuối cùng, một ví dụ về tính toán số đã được thực hiện để tìm ra các yếu tố ảnh hưởng đến chiều sâu của xu hướng đào xem xét phân bố hút không tuyến tính của đất không bão hòa.

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