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

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ABSTRACT.

Depth of an excavated trench plays a vital role on stability as well as economic efficiency 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 \( \beta \) (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 \( \beta \) 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
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 researchers regularly assume that the soil suction distribution is constant or linear with depth (Vanapalli, S.K., 2012., Whernham, 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**.

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

\[ H \geq (2 \div 5)2r = (4 \div 10)r \]  \hspace{1cm} (1)

and

\[ D > H + m \]  \hspace{1cm} (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):

\[ m \geq \frac{h}{\left(\gamma_s / \gamma_w - 1\right)} \]  \hspace{1cm} (3)

Where \( \gamma_s, \gamma_w \) 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, \( z_c \), the pore water pressure at the top is \(-z_c\gamma w\), 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).

\[
\begin{align*}
\frac{\partial z_c}{\partial \theta} &= \frac{\partial z_c}{\partial z} \\
\frac{\partial z_c}{\partial \theta^2} &= \frac{\partial z_c}{\partial \theta} + \frac{\partial^2 z_c}{\partial \theta^2} \\
\frac{\partial z_c}{\partial \theta^3} &= \frac{\partial z_c}{\partial \theta} + \frac{\partial^2 z_c}{\partial \theta^2} + \frac{\partial^3 z_c}{\partial \theta^3}
\end{align*}
\]

\( \theta = 0 \rightarrow z_c(\theta) = \max = k\gamma_n gD \)

\( \theta = D \rightarrow F_{hd}(\theta) = 0 \)

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

\[
F_{hd}(y) = \frac{A}{D}(D^2 - 2y^2 + y^3/D) \quad (5)
\]

or:

\[
F_{hd}(y) = AD(1 - y^3/D^3) \quad (6)
\]

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 \( AD = kD\gamma ng \) (at \( y = 0 \)) to zero (at \( y = D \)). The distribution of matric suction is showed in the Fig. 4.

\[
P_a = (\sigma_n - u_a)
\]

\[
= (\sigma_d - u_a)\cot g^2 \left( \frac{\pi}{4} - \frac{\phi'}{2} \right)
\]

\[
- 2C \cdot \cot g \left( \frac{\pi}{4} - \frac{\phi'}{2} \right)
\]

Where:

\[
\sigma_d = \gamma_d \cdot g \cdot y
\]

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, \( P_a \), which can be determined as follow (Bang, 1985; Terzaghi, 1941; Terzaghi et al., 1996; Wang, 2000):

\[
P_a = (\sigma_n - u_a) = (\sigma_d - u_a)\cot g^2 \left( \frac{\pi}{4} - \frac{\phi'}{2} \right) - 2C \cdot \cot g \left( \frac{\pi}{4} - \frac{\phi'}{2} \right) - 2(u_a - u_w)tg\phi_b
\]

Combination of Eq (9) and (7):

\[
P_a = (\sigma_n - u_a) = (\sigma_d - u_a)\cot g^2 \left( \frac{\pi}{4} - \frac{\phi'}{2} \right) - 2C' + (u_a - u_w)tg\phi_b \cot \left( \frac{\pi}{4} - \frac{\phi'}{2} \right) - 2(u_a - u_w)tg\phi_b \cot g \left( \frac{\pi}{4} - \frac{\phi'}{2} \right)
\]

Substitute Eq (5) into Eq (10):
\[ P_a = (\sigma_n - u_a) = (\sigma_a - u_a) \cot g^2 \left( \frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2[C' + \left( u_a - u_w \right)t g \varphi_b \cot \frac{\pi}{4} - \frac{\varphi'}{2} - 2t g \varphi_b \cot \frac{\pi}{4} - \frac{\varphi'}{2} - \frac{A}{D}(D^2 - 2y^2 + y^3/D) \] (11)

Substitute Eq (8) into Eq (11):

\[ P_a = (\sigma_n - u_a) = (g_d \cdot g \cdot y - u_a) \cot g^2 \left( \frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2[C' \cot g \left( \frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2t g \varphi_b \cot g \left( \frac{\pi}{4} - \frac{\varphi'}{2} \right) \cdot \frac{A}{D}(D^2 - 2y^2 + y^3/D) \] (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:

\[ P_A = \int_{0}^{H_t} P_a dy \] (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 \( u_a = 0 \):

\[ \sigma_d \cot g^2 \left( \frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2[C' \cot g \left( \frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2t g \varphi_b \cot g \left( \frac{\pi}{4} - \frac{\varphi'}{2} \right) \cdot \frac{A}{D}(D^2 - 2y^2 + y^3/D) \] (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:
\[ P_A = \int_{0}^{y} P_a \, dy = 0 \]  
\[ y \]

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:

\[ y_{kc} = f(\varphi', \varphi_d, u_a, \sigma_d, D, A) \]  
\[ (16) \]

### 4. Numerical calculation 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**

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective cohesion</td>
<td>( \gamma )</td>
<td>kN/m^3</td>
<td>18</td>
</tr>
<tr>
<td>Effective friction angle</td>
<td>( C' )</td>
<td>kPa</td>
<td>50</td>
</tr>
<tr>
<td>Effective friction angle associated with matric suction</td>
<td>( \varphi' )</td>
<td>Degree</td>
<td>22</td>
</tr>
<tr>
<td>Pore-water pressure coefficient</td>
<td>( \varphi_b )</td>
<td>Degree</td>
<td>14</td>
</tr>
<tr>
<td>Other parameters</td>
<td>( k )</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>Pore air pressure</td>
<td>( u_a )</td>
<td>kPa</td>
<td>0</td>
</tr>
</tbody>
</table>

#### 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 \( k_{kc} \) and level of ground water table**

<table>
<thead>
<tr>
<th>Depth of ground water table, ( D )</th>
<th>7</th>
<th>8</th>
<th>10</th>
<th>13</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_{kc} )</td>
<td>4.4</td>
<td>5.0</td>
<td>5.8</td>
<td>7.2</td>
<td>7.3</td>
</tr>
</tbody>
</table>

#### 4.3. Effect of effective friction angle

**Table 3. Relationship between \( k_{kc} \) and effective friction angle (Fig 6)**

<table>
<thead>
<tr>
<th>Effective friction angle, ( \varphi' )</th>
<th>10</th>
<th>18</th>
<th>26</th>
<th>30</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_{kc} )</td>
<td>4.85</td>
<td>4.34</td>
<td>3.87</td>
<td>3.57</td>
<td>3.32</td>
</tr>
</tbody>
</table>

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4.4. Effect of effective cohesion

Table 4. Relationship between $k_{kc}$ and effective cohesion (Fig 7).

<table>
<thead>
<tr>
<th>Effective friction angle, $C'$</th>
<th>kPa</th>
<th>20</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>85</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{kc}$</td>
<td>m</td>
<td>3.7</td>
<td>4.2</td>
<td>4.3</td>
<td>4.4</td>
<td>4.6</td>
</tr>
</tbody>
</table>

4.5. Effect of pore water pressure coefficient

Table 5. Relationship between $k_{kc}$ and pore-water pressure coefficient (Fig 8).

<table>
<thead>
<tr>
<th>Description</th>
<th>Values, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pore-water press. coef., $k$</td>
<td>1.0 1.2 1.5 1.7 2.0</td>
</tr>
<tr>
<td>$k_{kc}$</td>
<td>3.2 3.7 4.2 4.5 5.0</td>
</tr>
</tbody>
</table>

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

Fig. 6. Relationship between $k_{kc}$ and effective friction 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 $k_{kc}$ 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 soil 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.

REFERENCES


CÁC YẾU TỐ ẢNH HƯỞNG ÂNH HƯỞNG ĐẾN VIỆC GÂY TỦ VỌNG CỦA TRUYỀN LÁO HẤP DẪN TRONG ĐẤT KHÔNG BÊN VỮNG DO PHÂN BỘ HẤP THỤ KHÔNG TUYẾT ĐỎI

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TÓM TẮT
Độ sâu của rãnh đào đóng một vai trò quan trọng trong việc xác định cũng như hiệu quả kinh tế của rãnh mơ. Khi thiết kế và phân tích phỏng 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 bảo hóa. Do đó, độ sâu của rãnh không được hỗ trợ bởi anh hưởng đất, nên việc lựa chọn độ sâu đào thích hợp của rãnh trong điều kiện đất không bảo hóa, 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 đất không bảo hóa. Tuy nhiên, các công trình trước đây chỉ đề xuất 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, anh hưởng của phân bố lực hút đất 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 lực hút không tuyến tính của đất không bảo hóa.

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