



HỘI THẢO KHOA HỌC QUỐC TẾ PHÁT TRIỂN XÂY DỰNG BỀN VỮNG TRONG ĐIỀU KIỆN BIẾN ĐỔI KHÍ HẬU KHU VỰC ĐỒNG BẰNG SÔNG CỬU LONG

International Conference on sustainable construction development
in the context of climate change in the Mekong Delta (SCD2021)



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MỤC LỤC

STT	Tên bài	Trang
1	Phát triển xây dựng bền vững – cơ hội và thách thức trong điều kiện chủ động ứng phó với biến đổi khí hậu vùng đồng bằng sông Cửu Long Sustainable construction development – opportunities and challenges in the condition of active responsibilities to climate change area <i>TS . Trương Thị Hồng Nga</i>	3
2	Kinh nghiệm tổ chức nhà ở của châu Âu tại các vùng ngập nước tương đồng điều kiện đồng bằng sông Cửu Long European experience of housing organization in flood-prone areas similar to conditions of the mekong delta <i>Nguyen Tan Huy</i>	21
3	Kiến trúc trường học vùng đồng bằng sông Cửu Long ứng phó với biến đổi khí hậu theo hướng thích ứng, linh hoạt, đa chức năng <i>Doãn Minh Khôi, Doãn Thanh Bình, Nguyễn Mạnh Cường</i>	29
4	Tiếp cận cảnh quan văn hóa trong quy hoạch xây dựng đô thị thích ứng lũ lụt: nghiên cứu trường hợp sông Côn, sông Hà Thanh - thành phố Quy Nhơn - tỉnh Bình Định Cultural landscape along Con river and Ha Thanh river, Quy Nhon city, Binh Dinh – province: opportunities and challenges of urban development in flood adaptation <i>Phạm Việt Quang, Phạm Anh Dũng, Hoàng Anh, Cù Thị Ánh Tuyết</i>	37
5	Phân tích sự làm việc của vỏ hầm hai lớp The double - layer tunnel is operation is examined <i>Nguyễn Ngọc Huệ, Lê Minh Quang, Nguyễn Quang Quý</i>	51
6	Nghiên cứu phương pháp tính toán dao động riêng của hệ kết cấu dây cứng theo phương pháp nguyên lý cực trị gauss A research on calculation methods of natural vibrations of rigid cable structure system based on the gaussian extreme principle method <i>Phạm Hồng Hạnh, Phạm Văn Trung</i>	59
7	Phương pháp phase field với phân rã trực giao ten-xơ biến dạng mô phỏng hư hỏng kết cấu chứa vật liệu đẳng hướng Modeling of damage in structures containing isotropic material by phase field method with strain orthogonal decompositions <i>Vũ Bá Thành, Ngô Văn Thức</i>	67
8	Một số giải pháp trong khai thác nước ngầm bằng bãi giếng nhằm giảm thiểu hạ thấp mặt đất Some solutions in groundwater exploitation by good yards for reduction lowering the ground <i>Nguyễn Xuân Mãn, Nguyễn Duyên Phong</i>	75
9	A case study on the determination of the excavated trench depth in unsaturated soil constructed by trench method without supporting structures <i>Nguyen Xuan Man, Nguyen Duyen Phong</i>	83

10	Xác định các tham số neo đất phù hợp giữ ổn định bờ sông tránh sạt lở Determination of the appropriate parameters of soil bolts for river bank reinforcement to reduce landslide <i>Trần Tuấn Minh, Nguyễn Duyên Phong, Ngô Văn Thúc</i>	89
11	Nghiên cứu xác định phạm vi vùng ảnh hưởng khi thi công khoan kích ngầm trong điều kiện đất yếu tại khu vực đồng bằng sông Cửu Long Estimating the influence zone induced by pipejacking in the Mekong Delta soft soil conditions <i>Vũ Minh Ngạn, Lại Thanh Nhân, Hoàng Đình Phúc, Phạm Đức Thọ</i>	97
12	Nghiên cứu xây dựng mô hình số đánh giá hiệu quả xử lý nền đất yếu bằng cọc hỗn hợp vật liệu cát biển - xi măng - tro bay 3D numerical modeling to estimate the effectiveness of sea sand - cement - fly ash columns improved soft soil <i>Pham Van Hung, Ta Duc Thinh, Nguyen Thanh Duong, Bui Anh Thang</i>	105
13	So sánh phương án cọc trong xử lý nền công trình thủy lợi Comparison of pile foundation alternatives in hydraulic structure <i>Dương Nghĩa Nhân, Trần Văn Tỷ, Lâm Tấn Phát, Võ Văn Dấu</i>	113
14	Tiềm năng sử dụng tro trấu trong cải tạo, xử lý đất yếu ở đồng bằng sông Cửu Long Potential use of rice husk ash in soft soil improvement in Mekong Delta <i>Nguyễn Thành Dương</i>	123
15	Công trình ngầm thành phố và các giải pháp địa kỹ thuật Urban underground structures and geotechnical measures <i>Nguyen Ngoc Long Giang, Nguyen Quang Phich, Nguyen Van Manh, Phạm Văn Kiên, Dao Hong Hai</i>	133
16	Phát triển đô thị thông minh bền vững trong bối cảnh cuộc cách mạng Công nghệ 4.0 và khởi nghiệp sáng tạo tại một số đô thị miền Nam Việt Nam Sustainable Smart City Development in The Context of the 4.0 Technology Revolution and Innovative Start Up in Some Cities in the South of Vietnam <i>Pham Kien, Tran Van Thien, Tran Nguyen Nha Chi, Nguyen Quang Phich</i>	141
17	Mô phỏng số về lan truyền vết nứt trong dầm bê tông Numerical simulation of crack growth in the concrete beams <i>Nguyễn Văn Mạnh, Nguyễn Quang Phích, Nguyễn Ngọc Long Giang</i>	153
18	Nghiên cứu và phát triển bê tông tính năng siêu cao trong xây dựng Research and development of Ultra-High performance concrete in construction <i>Nguyễn Xuân Mãn, Nguyễn Duyên Phong, Phạm Mạnh Hào</i>	159
19	Phân tích tính chất phá hủy của dầm bê tông nứt mối sử dụng nano-silica khi chịu uốn: Thực nghiệm và mô phỏng On the analysis fracture properties of notched concrete beams incorporating nano-silica in bending test: Experimentation and simulation <i>Phạm Đức Thọ, Vũ Minh Ngạn, Hoàng Đình Phúc, Ngô Văn Thúc</i>	167
20	Khả năng sử dụng cốt liệu lớn tái chế từ bê tông phế thải để thay thế cốt liệu tự nhiên trong xây dựng công trình The ability to use coarse recycled aggregates concrete for replacement of natural aggregates in building construction <i>Dang Quang Huy, Bui Anh Thang, Pham Duc Tho</i>	173
21	Đánh giá mô hình khí hậu toàn cầu và viễn thám để ứng phó với biến đổi khí hậu tại khu vực đồng bằng sông Cửu Long Evaluation of global climate models and remote sensing technology in response to climate change in the vietnamese mekong delta	181

- 22 Ảnh hưởng của biến đổi khí hậu đến ngập lụt thành phố Cần Thơ - các giải pháp kiểm soát và thích ứng 191
Impact of climate change on Can Tho city - The high-risk flood area division and flooding control and adaptation
Trần Thanh Thảo, Lê Thị Bạch Tuyết, Giang Văn Tuyển, Trần Quang Nhật
- 23 Ứng dụng mô hình SWMM để xuất giải pháp giảm ngập cho quận Bình Thủy, thành phố Cần Thơ 199
Applying SWMM model to propose solutions for flood mitigation at Binh Thuy district, Can Tho city
Nguyễn Ngọc Toàn, Nguyễn Đình Giang Nam, Nguyễn Võ Châu Ngân
- 24 Nghiên cứu nguyên nhân gây sạt lở bờ sông Nhu Gia tại địa bàn huyện Mỹ Tú, tỉnh Sóc Trăng 209
Study on causes for erosion of Nhu Gia River in My Tu district, Soc Trang Province
Nguyễn Thái An, Phạm Quốc Thanh, Trần Văn Tỷ, Lê Hải Trí, Huỳnh Thị Cẩm Hồng, Đinh Văn Duy
- 25 Đánh giá tính tổn thương xâm nhập mặn nguồn tài nguyên nước dưới đất tỉnh Trà Vinh 217
Đào Hồng Hải, Daniela Cid Escobar, Sergio Gil Villalba, Tibor Stigite, Nguyễn Việt Kỳ
- 26 Some issues in the planning, artificial recharge, exploiting and protecting groundwater resources in Tra Vinh province 225
Nguyen Viet Ky, Dao Hong Hai
- 27 Photocatalytic performance of TiO₂ nanoparticle doped by transition metal ion 233
Jittinat Sirichokthanasarp, Patcharaporn Phuinthiang, Dang Trung Tri Trinh, Duangdao Channei, Kantapat Chansaenpak, Auppatham Nakaruk, Wilawan Khanitchaidecha
- 28 Đánh giá tổn thương do tác động biến đổi khí hậu – trường hợp nghiên cứu tại tỉnh Trà Vinh 243
Assessment the vulnerability on climate change impact– case study in tra vinh province
Nguyễn Quốc Hậu, Trịnh Công Luận, Nguyễn Thị Hồng Điệp
- 29 Đánh giá hiệu quả hệ thống giao thông - thủy lợi đáp ứng tiêu chí nông thôn mới của huyện Long Mỹ, tỉnh Hậu Giang 251
Evaluation of the effectiveness of the transportation - irrigation system adapt to the new rural area criteria at Long My district, Hau Giang province
Ngô Quốc Phục, Trương Yến Linh, Ngô Thị Ngọc, Nguyễn Võ Châu Ngân
- 30 Research on urban infrastructure solutions Adapting to climate change conditions in HCMC and the Mekong Delta 261
Ngo Trung Duong, Vo Anh Tuan

A CASE STUDY ON THE DETERMINATION OF THE EXCAVATED TRENCH DEPTH IN UNSATURATED SOIL CONSTRUCTED BY TRENCH METHOD WITHOUT SUPPORTING STRUCTURES

Nguyen Xuan Man, Nguyen Duyen Phong

ABSTRACT:

The depth of an excavated trench plays a vital role in the instability 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, the excavated trench is usually located above the groundwater table or under unsaturated soil conditions. Therefore, the depth of the 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 conditions. 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 the 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 the nonlinear suction distribution of unsaturated soils.

KEYWORDS: *Determination, Excavated trench depth, Soil mechanics, Supporting structures.*

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1. INTRODUCTION

Previous research indicated that critical depth (H) or ratio of depth and width of the 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 requirements and economic effectiveness.

The L/H ratio controls the angle of the open trench, hence the amount of excavation work required. The less the value of β (as shown in Fig 1) is, the higher stability of the open trench; however, the larger the amount of excavation work that needs to be done. Economically side speaking, once the value of β equals 90° the amount of excavation work required is lowest, hence the highest of the

effectiveness of economic. Despite this, the stability of the open trench must be taken into account. It is widely observed that under this condition $\beta = 90^\circ$, 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 shortcomings might be seen as follows (Ou, C.Y., 2006):

- Due to the existence of the temporary structures, the construction area of underground construction is reduced;
- It is costly since temporary structures are needed;
- Progress of construction work is significantly affected, even much longer as compared to that in case of without using temporary structures.

In addition, the excavated trench is usually positioned above the groundwater table or under unsaturated soil conditions. Earlier researchers regularly assume that the soil suction distribution is constant or linear with depth (Vanapalli, S.K., and Oh, W.T., 2012), 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.

2. MATRIC SUCTION IN UNSATURATED SOIL

To find out an applicable value of the depth of an open trench, a typical cross-section of the trench is made as shown (Fig. 1).

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 M., 2015).

At the groundwater level, the pore water pressure is zero and decreases (becomes negative) as the capillary zone goes up. Because of the presence of the negative pore water pressure,

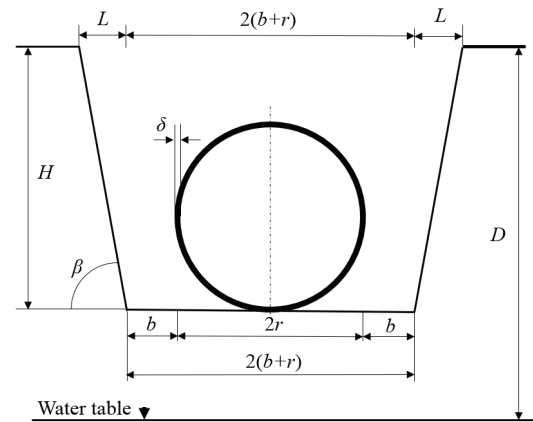


Fig. 1. A typical cross-section of an open trench

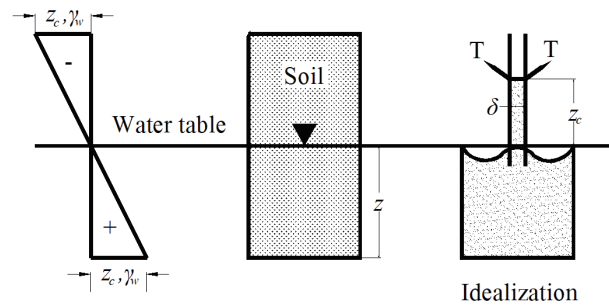


Fig. 2. Simulation of capillary in soil

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 D.G., 1996; Fredlund D.G., and Rahardjo H., 1993; Fredlund D.G., et. al., 1978; Fredlund D.G., et. al., 2012; Fredlund D.G., et. al., 1996) stated that the 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 the 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 the groundwater-surface such as infiltration, the

matric suction profile will be drawn to the right (matric suction reduces) (Bishop A.W., 1959; Bishop A.W., and Donald I.B., 1961; Bishop A.W., and Blight G.E., 1963). 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) (Lambe T.W. and Whitman R.V., 2008).

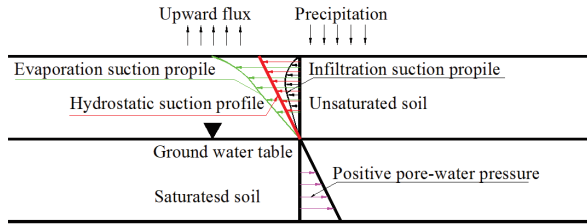


Fig. 3. Matric suction profile in horizontally layered unsaturated soil profiles under various surface flux boundary conditions

From the distribution of matric suction, it's found that the matric suction profile varies with depth and is 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 (Puller, M., 2015; Whenham V., et. al., 2007):

$$F_{hd}(y) = a + by + cy^2 + dy^3 \quad (1)$$

Where: y is the considered depth of open trench; F_{hd} is the function of matric suction varies with depth. The equation (1) must be met the following conditions:

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

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

By considering and comparing with the practical condition, the equation (1) can be rewritten as:

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

$$F_{hd}(y) = AD(1 - 2y^2/D^2 + y^3/D^3) \quad (3)$$

Where $A = k\gamma_w g$, 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 equations (2), (3), the magnitude of matric suction is decreased from a value of $AD = kD\gamma_w g$ (at $y = 0$) to zero (at $y = D$). The distribution of matric suction is shown (Fig. 4).

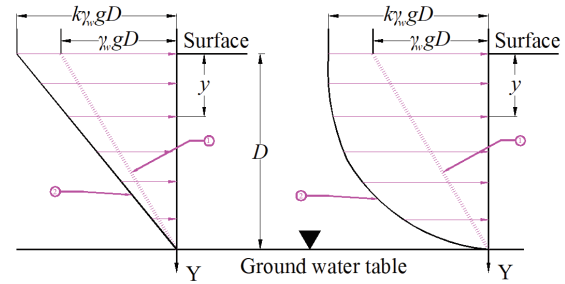


Fig. 4. The distribution of matric suction with depth. (1) represent the surface of hydrostatic suction; (2) the distribution line of matric suction

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, P_a , which can be determined as following (Sangchul Bang A.M., 1985; Terzaghi K., 1941; Terzaghi K., et. al., 1996; Wang Y.Z., 2000; Terzaghi K.V., 1936):

$$P_a = (\sigma_n - u_a) \cot g^2 \left(\frac{\pi}{4} - \frac{\phi'}{2} \right) - 2C \cot g \left(\frac{\pi}{4} - \frac{\phi'}{2} \right) \quad (4)$$

$$\sigma_d = \gamma_d \cdot g \cdot y \quad (5)$$

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

$$C = C' + (u_a - u_w) \tan \phi_b \quad (6)$$

Combination of equations (5) and (6):

$$P_a = (\sigma_n - u_a) = (\sigma_d - u_a) \cot g^2 \left(\frac{\pi}{4} - \frac{\phi'}{2} \right) - 2[C' + (u_a - u_w) \tan \phi_b] \cot g \left(\frac{\pi}{4} - \frac{\phi'}{2} \right) - 2(u_a - u_w) \tan \phi_b \cot g \left(\frac{\pi}{4} - \frac{\phi'}{2} \right) \quad (7)$$

Substitute equation (4) into equation (7):

$$P_a = (\sigma_n - u_a) = (\sigma_d - u_a) \cot g^2 \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2 \left[C' + (u_a - u_w) \operatorname{tg} \varphi_b \right] \cot g \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2 \operatorname{tg} \varphi_b \cot g \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) \cdot \frac{A}{D} (D^2 - 2y^2 + y^3/D) \quad (8)$$

Substitute equation (5) into equation (8):

$$P_a = (\sigma_n - u_a) = (\gamma_d \cdot g \cdot y - u_a) \cot g^2 \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2C' \cot g \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2 \operatorname{tg} \varphi_b \cot g \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) \times \frac{A}{D} (D^2 - 2y^2 + y^3/D) \quad (9)$$

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

$$P_A = \int_0^{H_t} P_a dy \quad (10)$$

3.2. Determine the magnitude of the depth of the open trench

The distribution of active earth pressure can be divided into two regions, one is a tensile region, the other one is the compressive region. Two of these regions are separated at a depth of y_k . In the tensile region (from the surface to a depth of y_k), the active earth pressure is negative, which causes soil mass behinds the retaining wall tends to move away from the retaining wall. The magnitude of y_k may be estimated by combination equation (10) and equations (2), (3), together with a condition of $P_a = 0$ and $u_a = 0$:

$$\sigma_d \cot g^2 \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) - 2 \operatorname{tg} \varphi_b \cot g \left(\frac{\pi}{4} - \frac{\varphi'}{2} \right) \cdot \frac{A}{D} (D^2 - 2y^2 + y^3/D) \quad (11)$$

After working out the equation (11), 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 the depth of the open trench, y_{kc} , can be determined by solving the following equation:

$$P_A = \int_0^y P_a dy = 0 \quad (12)$$

By substituting equation (8) into equation (12), and working out the equation (12) with y as the variable, the y_{kc} can be derived, and its value is a function of:

$$y_{kc} = f(\varphi', \varphi_b, u_a, \sigma_d, D, A) \quad (13)$$

Take the input data from Table.1 to calculate P_a in (12) and then transform will give us the explicit value in (13).

4. NUMERICAL CALCULATION RESULTS AND DISCUSSION

4.1. Numerical Calculation

Table 1. Soil parameters used in this paper

Description	Symbol	Unit	Value
Effective cohesion	γ	kg/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

Numerical calculation is carried out using the concept of equation (13), in which the input parameters of soil sample such as physical and mechanical properties of the studied soil are shown (Table 1). The study soil sample was collected in a construction site located in the Southeast of Vietnam.

4.2. Effect of level of the groundwater table

By changing the level of groundwater table (D), the relationship between the 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 the groundwater table

Depth of groundwater 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 k_{kc} effective friction angle (Fig. 6)

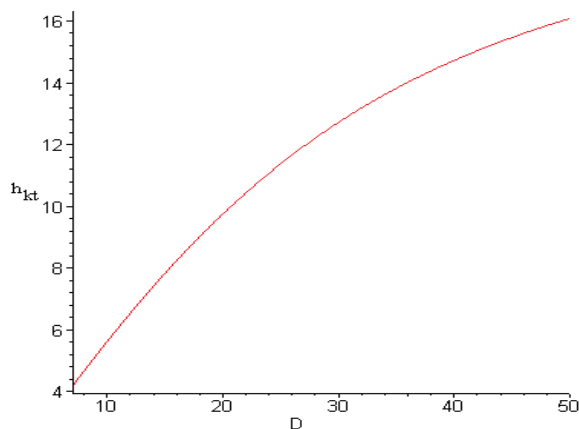
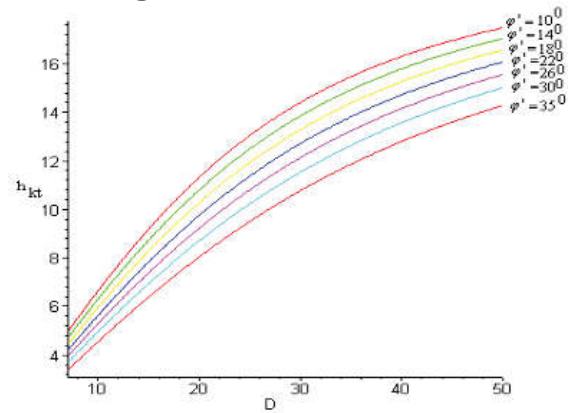
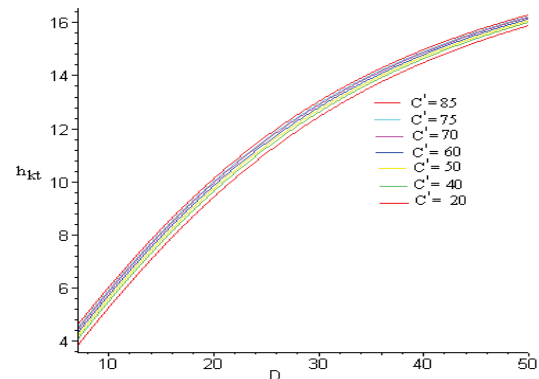
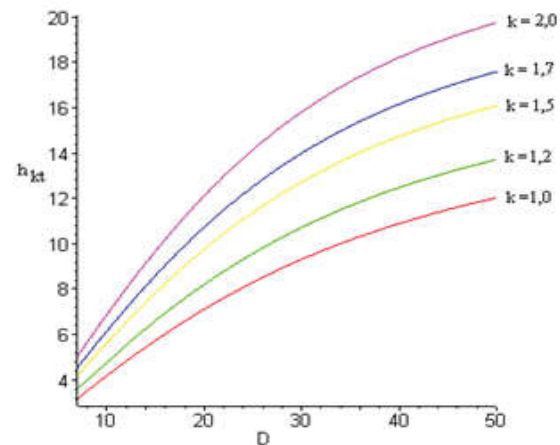
Effective friction angle, φ'	10	18	26	30	35
k_{kc}	4.85	4.34	3.87	3.57	3.32

4.4. Effect of effective cohesion**Table 4.** Relationship between k_{kc} and effective cohesion (Fig. 7)

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

4.5. Effect of pore water pressure coefficient**Table 5.** Relationship between k_{kc} and pore-water pressure coefficient (Fig. 8)

Description					
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 the groundwater table**Fig. 6.** Relationship between k_{kc} and level of the groundwater table**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 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 a certain value,

the value of k_{kc} is almost constant and tends to reach the critical value.

- Under the same conditions, the unsupported depth of an open trench, k_{kc} are as follows:

+ The value of k_{kc} decreases with an increase of effective friction angle;

+ The value of k_{kc} does not significantly increase as the effective cohesion increases;

+ The value of k_{kc} is notably increased as the pore-water pressure coefficient increases.

5. CONCLUSION

The paper aim at pointing 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 an optimum design of an 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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Bộ Xây Dựng; Trường đại học Xây dựng Miền Tây; Trường đại học Xây dựng; Trường đại học Bách Khoa – ĐHQG TP. Hồ Chí Minh; Hội Địa chất Công trình và Môi trường Việt Nam; Hội Kết cấu và công nghệ xây dựng Việt Nam; Hội Bê tông Việt Nam

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