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BEHAVIOR OF STABLIZING SLOPES WITH SAND TRENCH IN COHESIVE SOIL DUE TO STRIP FOOTING

Mostafa Abdou Abd El-Naiem

Lecturer, Civil Eng .Department, Faculty of Eng., Assiut University, Assiut, Egypt

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It is well known that many slope failure, which occur every year in the world, are triggered by different loads such as own weight, structures, vehicles, rainfall, or seismic loads. The mechanisms of slope movements due to these loads are not completely understood. Sand trench may be designed to restrain soil movements when used to stabilize cohesive soil slopes or potential landslides. The lateral loads resulting from the soil movement induce stresses and deformations in the sand trench which may lead to its damage. The effects of factors such as type of soil soft, medium, and stiff clay, slope angle β, and position of sand trench on the behavior of stabilizing slopes have been investigated under the effect of line load from strip footing on the road level. The depth of sand trench has been chosen deeper than the expected slip failure surface. A sand trench to improve the behavior of stabilizing slopes has been used. The depth of sand trench has been chosen deeper than the expected slip failure surface which determined according any traditional methods. The selected sand trench depth of 6 m below base point of slope is suitable. From this study it can be found that, the additional deformations include horizontal and vertical displacements are clearly affected with existing sand trench in slope zone. Also, the best position of sand trench when it is constructed in the beginning of slope from top level (horizontal distance X = 0.0 m). The best effect of sand trench appears in the case of soil profile consists of soft clay. The slope angle β influences in the behavior of stabilizing slopes and in the effect of sand trench. Also, the effect of cohesion on the behavior of stabilizing slopes with and without sand trench has been studied. Critical points lie on the surface line of slope such as base, mid, and top points have been chosen to determine the behavior of stabilizing slope.

KEYWORDS: *Stability of slopes, Cohesive soil, Displacement, Sand, Clay, Finite Element Method.*

1. INTRODUCTION

The increasing need for safe areas for human activities requires a major improve in the research on slope behavior, with particular reference to risk assessment. Engineering analysis of slope stability includes three separate but interrelated phases: (a) experimental strength measurements, (b) determination of a strength envelope that best fits the experimental results, and (c) formal limiting equilibrium analysis using the resulting strength envelopes. Studying the interrelations between theses phases leads to an integrated approach to slope stability analysis [1]. Using the finite element method, a cohesive horizontal ground is sequentially excavated until the stress state along a potential slip surface of the excavated slope reaches the critical state. Mobilized friction angle and stress ratio contours in the slope generated by the finite element solution are examined to quantify the part of the slip surface that undergoes extension resulting in anisotropic conditions. It is shown that excavated slopes display anisotropic behavior and that the consideration of strength anisotropy in slope stability analysis is essential [2]. Hwang *et al.* (2002) stated that since Fellenius introduced the limiting equilibrium concepts for slope stability analysis in the 1920s, a variety of analytical techniques have been proposed to quantitatively assess the stability of slopes. These techniques can generally be divided among four methods: limiting equilibrium, limit analysis, variational, and finite element methods [2]. They mentioned that significant progress has been made in solutions based on the limit analysis and variational methods, and finite element analysis has become attractive due to its ability to simulate field conditions effectively with faster computers, the limiting equilibrium method continues to be the most commonly used solution technique in practice for slope stability evaluations. In most slope stability limiting equilibrium solutions, the soil is treated as a homogeneous isotropic material with constant strength parameters. In some cases, linearly increasing strength with depth has been used throughout the slope, or in the layers into which the slope is divided arbitrarily. However, most natural soil deposits exhibit anisotropic behavior [2]. The undrained shear strength along a failure surface in two-dimensional (2-D) slopes can be determined from three different types of tests, namely, plane strain compression (PSC), plane strain extension (PSE), and direct simple shear (DSS) tests, to better represent the loading conditions on the slip surface [2]. If excavated slopes are to be modeled, the initial stress distribution in the horizontal ground before excavation is clearly defined by the K_o (coefficient of lateral earth pressure at-rest) conditions [2]. A stress state at an element along the slip surface is considered to be in compression when the excavation process brings the ratio of horizontal stress to vertical stress in that element to be less than K_o. On the other hand, when this ratio is greater than K_o, the element is considered to be in extension. Since the major principal stress in the compression mode leans to ward the vertical direction rather than the horizontal and the end point of the compression zone along the slip surface is located at some distance from the point where the tangent to the slip surface is horizontal, it is unlikely that the simple shear zone will be in the assumed compression zone. Hwang *et al.* [2] mentioned that it may not be easy to discern the simple shear state from the extension state with the reference of K_o, since the major principal stress in both cases leans toward the horizontal. However, in that case, inclusion of the zone of simple shear into the assumed extension zone is acceptable because it is generally on the conservative side.

The evaluation of slope stability by the limit equilibrium method involves calculating the factor of safety for a given slide surface and searching for the critical slip surface that has the lowest factor of safety. When the potential slip surface can be considered circular in shape, the factor of safety may be obtained by widely used methods and is not a difficult task to locate the critical slip circle with sufficient accuracy because the search involves only coordinates of the center of the circle and its radius [3]. It has been widely recognized that slip surfaces should not be restricted to a circular shape for most real problems, especially in the case of soils with weak layers or rocks with discontinuities [3]. Abdelrahman *et al.* [4] analyzed of stabilizing slopes using vertical piles. They studied the important parameters that affect the behavior and factor of safety of piles in slopes. These parameters are; the pile position, pile diameter and depth, soil properties, soil layer thickness and surcharge load.

2. NUMERICAL PROCEDURES

In the present study, the behavior of slopes have different angles of inclination has been studied. The study is conducted using a 2-D finite element model. The finite element computer program FINAL (Swoboda, [5]) has been used in this study. This finite element model takes into account the effects of the vertical overburden pressure and the lateral earth pressure using two methods of solution, *Dead Loads* or *Initial Stresses*, in this analysis, Dead Loads method has been used. Also, this program takes into account the nonlinear properties of the soils. The dimensions of the 2-D model have been determined in order to eliminate the effect of boundary conditions and the size effect in the prediction of the performance of the slope. The geometry of a typical model and finite element mesh adopted for the analysis are shown in Figures 1 and 2, respectively. The soils of slope and that of trench are simulated using appropriate finite elements. The soils were modeled using 2-D elements, called an LST element, (Linearly Varying Strain Triangular Element), which has six nodes, each having two translation degrees of freedom as mentioned by Swoboda [6], and shown in Fig. 2. The left and right vertical sides of the model were constrained horizontally, and the bottom horizontal boundary was constrained in both the horizontal and vertical directions as shown in Figure 1.

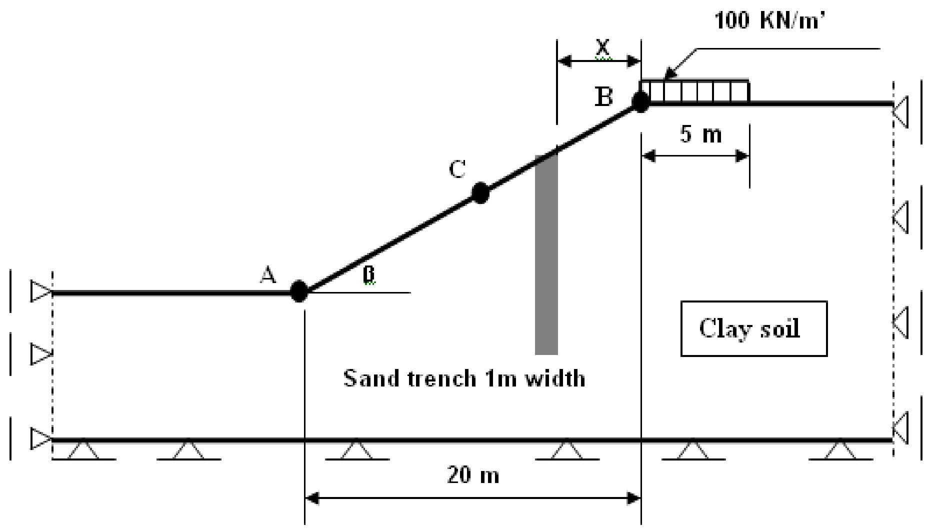


Figure 1. Layout of the model

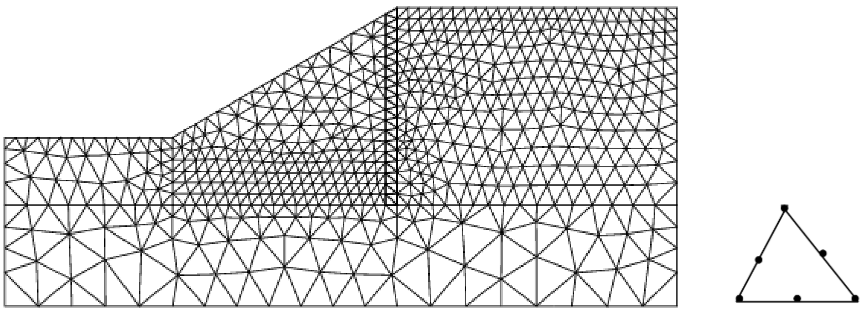


Figure 2. Finite element model

3. GEOTECHNICAL ANALYSIS

In the present study, three slopes with different slope angle (β) have been studied. Three soil profiles have been investigated. The first consists of homogenous soft clay has cohesion (C =10 KN/m^2); the second is homogenous medium clay (C = 40 KN/m^2); whereas the third is homogenous stiff clay (C = 70 KN/m^2). Some of the soil properties have been taken as mentioned by Abdelrahman *et al.* [4] and tabulated as shown in Table 1. These values are in the range of the soft, medium, or stiff clay as stated in the Egyptian code of soil mechanics and foundations design [7]. The value of the modulus of elasticity is assumed to be 500 C, [4]. Sand trench 1 m width was used to improve the behavior of stabilizing slope. The depth of sand trench has been chosen deeper than the expected slip failure surface which determined according any traditional methods. The selected sand trench depth of 6 m below base point of slope, (point **A**), is suitable.

3.1. Material Constants

In this study, the material constants of clay soil and sand trench were chosen as mentioned with Abdelrahman *et al.* [4] to represent the real properties of soil profile. These constants such as modulus of elasticity (*E*), Poisson's ratio (*ν*), density (*γ*), angle of internal friction (ϕ), and cohesion (C) for different elements of the model are tabulated in Table 1.

Table 1. Soil properties (after Abdelrahman *et al.* [4])

Parameter	Clay	Sand
Dry unit weight γ (KN/m^3)	16	17
Wet unit weight γ (KN/m^3)	18	20
Young's modulus E (KN/m^2)	500 C	2.1x10^7
Poisson's ratio ν	0.49	0.3
Cohesion C (KN/m^2)	10,40,70	0
Angle of internal friction ϕ	0	31
Type of behavior	Undrained	Drained

The external load applied is a line load on the top of slope (ground surface level), where this load is a strip footing load with intensity of 100 KN/M'.

3.2. Study Cases

There are different cases are adopted to study the behavior of stabilizing slopes under the effect of strip footing. These cases include slope angleβ, position of sand trench, and type of soil profile, soft, medium or stiff clay. There are three main groups of study cases according to slope angle β. These values for slope angle (β) have been taken 45^o, 30^o, and 20^o. Each group include eight study cases, where four for soft clay, two for medium clay, and two for stiff clay as tabulated in Table 1. Also, different values of horizontal distance X of sand trench measured from the top edge of slope (point B), as shown in Figure 1, have been taken into consideration as mentioned in Table 2. The details of all study cases are presented in Table 2.

Table 2. Detail of study cases

Case		Group		
		$\beta = 45^o$	$\beta = 30^o$	$\beta = 20^o$
Type of clay	Case No.	X	X	X
Soft clay C = 10 KN/m^2	1	*	*	*
	2	0.0	0.0	0.0
	3	2.0	2.0	2.67
	4	4.0	4.0	5.33
Medium clay C = 40 KN/m^2	5	*	*	*
	6	0.0	0.0	0.0
Stiff clay C = 70 KN/m^2	7	*	*	*
	8	0.0	0.0	0.0

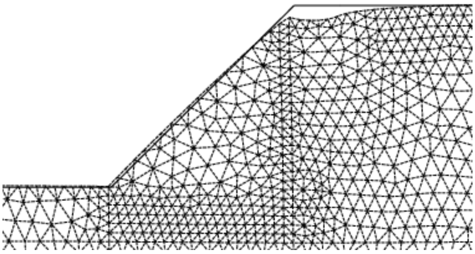
Where * Means original soil profile without sand trench,
β is slope angle,
C is the cohesion, and
X is the horizontal distance of sand trench as shown in Figure 1.

4. ANALYSIS OF RESULTS AND DISCUSSIONS

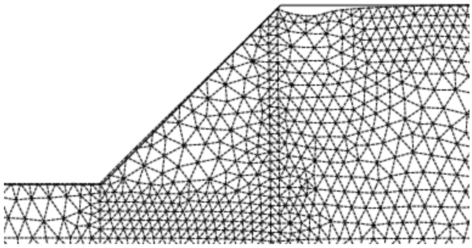
To study the behavior of stabilizing slope under the effect of strip footing on its top level and other previous parameters, the displacements in the critical points on the slope line have been determined. These critical points such as bottom, top, and midpoint whose named **A, B,** and **C**, respectively, were chosen as shown in Figure 1. To analyze and illustrate the behavior of stabilizing slopes, many Figures such as deformation shapes and displacements were plotted.

4.1. Deformation Shapes (case of soft clay)

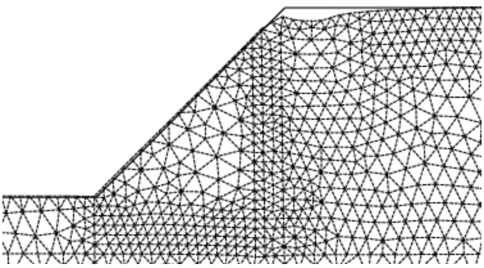
The additional deformation shapes for slopes in soft clay soil due to strip footing on its top level and other previous parameters were illustrated as shown in Figures 3 and 4.



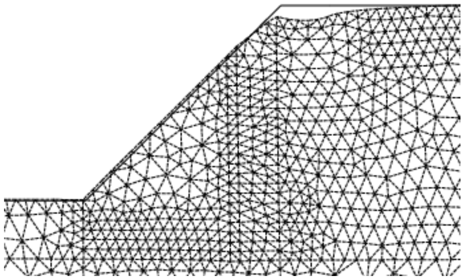
(a) Without sand trench



(b) With sand trench, X = 0.0

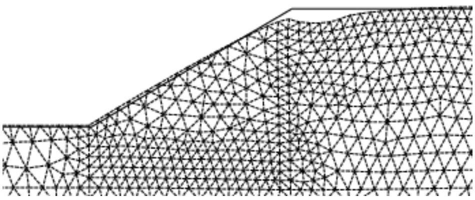


(c) With sand trench, X = 2.0 m

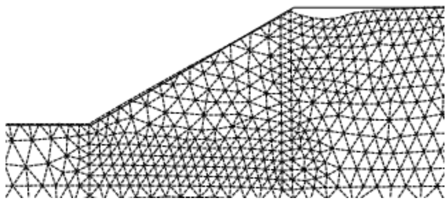


(d) With sand trench, X = 4.0 m

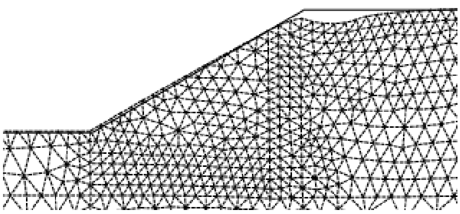
Figure 3. Deformation shapes for slope ($\beta = 45^o$) due to strip footing, case of soft clay (C = 10 KN/m^2)



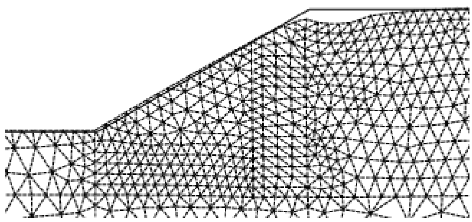
(a) Without sand trench



(b) With sand trench, X = 0.0



(c) With sand trench, X = 2.0 m



(d) With sand trench, X = 4.0 m

Figure 4. Deformation shapes for slope ($\beta = 30^o$) due to strip footing, case of soft clay (C = 10 KN/m^2)

These Figures represent the additional deformation shapes for two slope angles β = 45^o and 30^o, respectively. Also, in the case of original soil without and with sand trench and three cases of sand trench position, X= 0.0, 2.0 m, and 4.0 m were illustrated in Figures 3 and 4, a, b, c, and d, respectively. It can be shown that the deformations decrease as slope angles β decrease. It can be found that, in the case of soil without sand trench, the deformations are more than other cases, and then decrease with existing sand trench. It can be noticed that the deformation affects with sand trench position, where it decreases as distance X increases. Also, it can be found that the effect of sand trench may be neglected when distance X ≥ 2.0 m, where the results approximately return to the case of soil without sand trench. The same analysis and discussions were found in the case of slope angle β = 20^o, where the deformations were less than other cases.

4.2. Displacements (case of soft clay)

For all considered study cases of soft clay soil, the additional horizontal and vertical displacements were plotted in the Figures 5 to 12.

a) Horizontal displacements

Figures 5, 6, and 7 show the relationships between distances X of sand trench and additional horizontal displacements for slopes have angles of inclination β equal to 45^o, 30^o, and 20^o, respectively. The values of displacements corresponding to distance X before 0.0 denote the displacement values in the case of slope without sand trench (original case). It can be noticed that the additional horizontal displacements in the case of slope angle β = 45^o are more than those values obtained in other slopes, especially, in the original case and at point C in other cases of slope with sand trench.

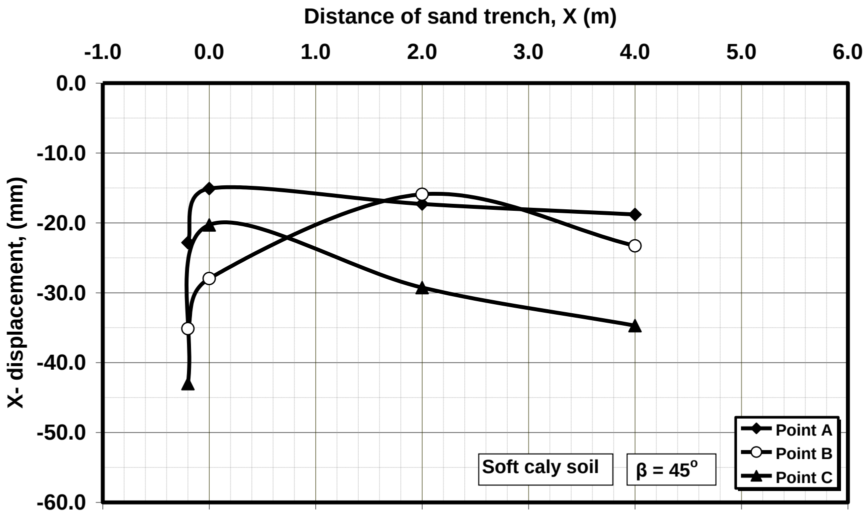


Figure 5. Horizontal displacements for slope (β = 45^o) due to strip footing, case of soft clay (C = 10 KN/m^2)

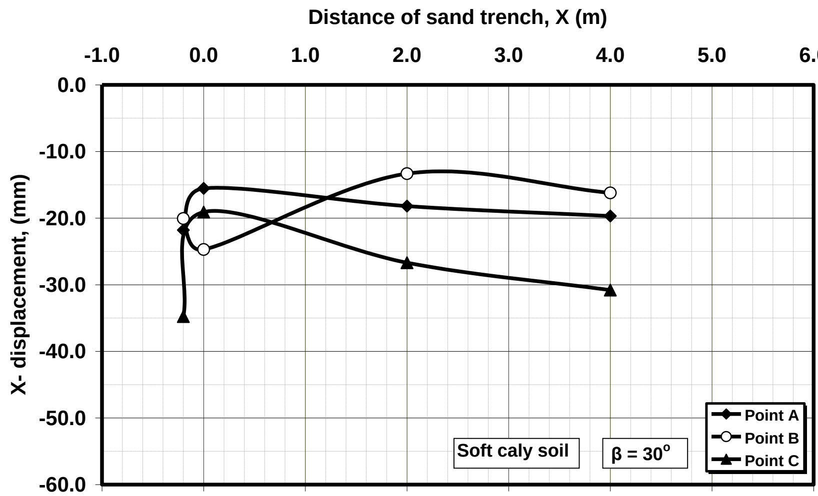


Figure 6. Horizontal displacements for slope (β = 30°) due to strip footing, case of soft clay (C = 10 KN/m^2)

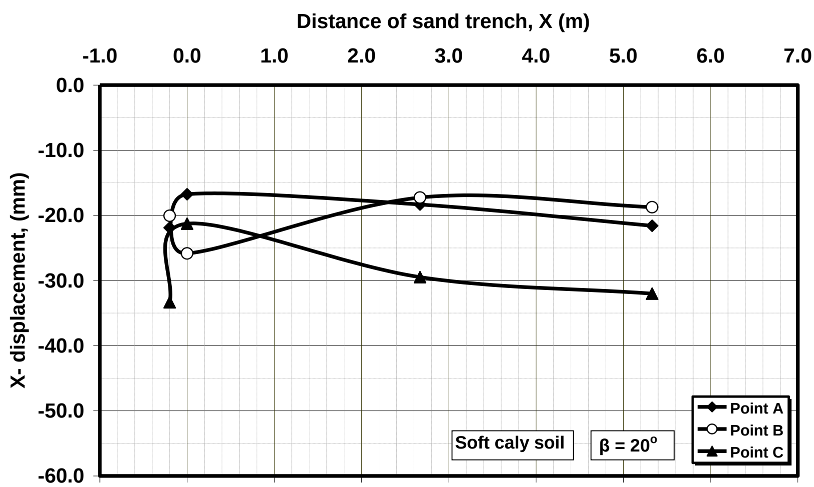


Figure 7. Horizontal displacements for slope (β = 20°) due to strip footing, case of soft clay (C = 10 KN/m^2)

It can be found that point C is more affected with existing sand trench than other points. This affect is clearly appear when sand trench at distance X = 0.0, after that the values of additional horizontal displacement return approximately to the original values without sand trench effect.

Figure 8 shows the relationship between horizontal displacement and slope angle β. It can be found that, in the case of slope angle β = 20° or 30°, the case of distance X = 0.0 represents the critical case, whereas, in the case of angle β = 45°, the case of original soil without sand trench represents the critical case.

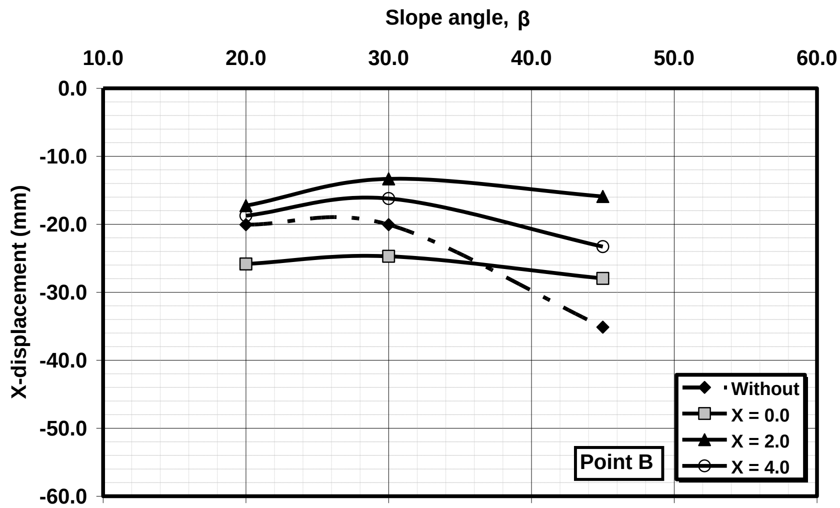


Figure 8. Horizontal displacements versus slope angle β for point B due to strip footing, case of soft clay (C = 10 KN/m^2)

b) Vertical displacements

Figures 9, 10, and 11 show the relationships between distances X of sand trench and additional vertical displacements for slopes have angles of inclination β equal to 45^o, 30^o, and 20^o, respectively. The values of displacements corresponding to distance X before 0.0 denote the additional vertical displacement values in the case of slope without sand trench (original case).

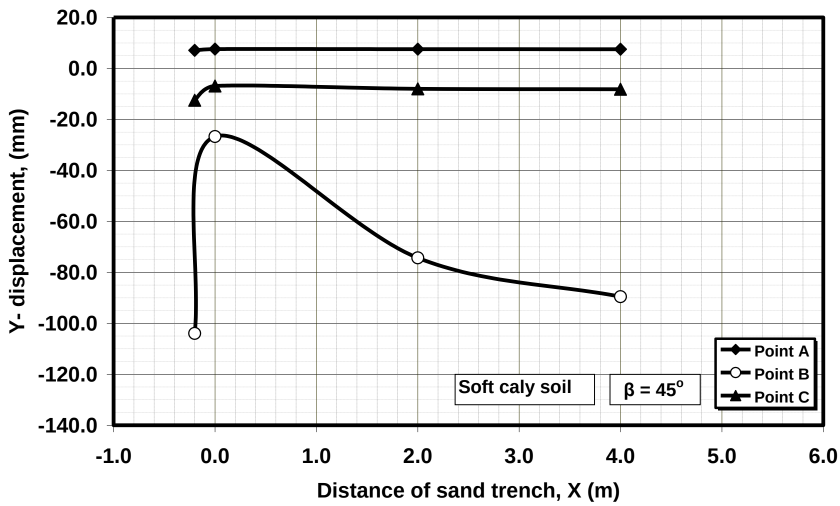


Figure 9. Vertical displacements for slope (β = 45^o) due to strip footing, case of soft clay (C = 10 KN/m^2)

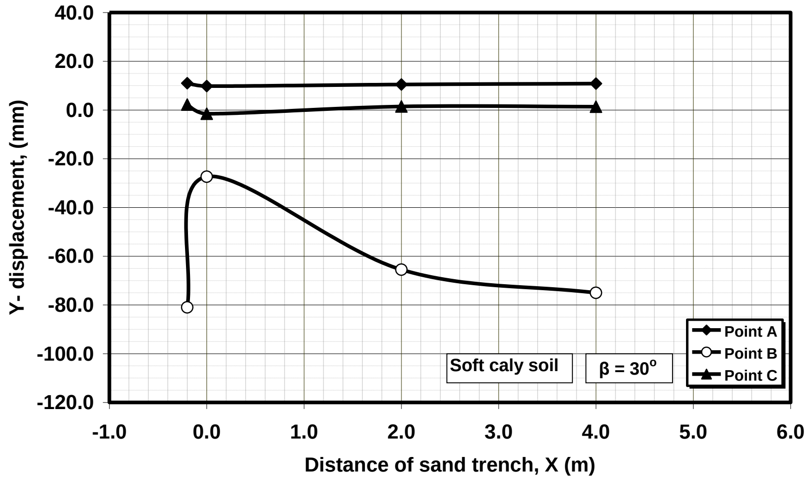


Figure 10. Vertical displacements for slope ($\beta = 30^o$) due to strip footing, case of soft clay (C = 10 KN/m^2)

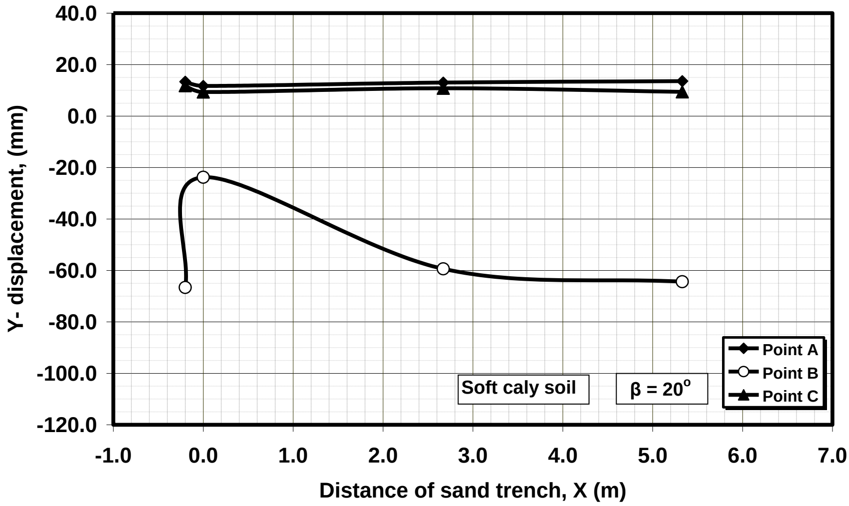


Figure 11. Vertical displacements for slope ($\beta = 20^o$) due to strip footing, case of soft clay (C = 10 KN/m^2)

From these Figures, It can be noticed that the additional vertical displacements in the case of slope angle $\beta = 45^o$ are more than those values obtained in other slopes, especially, in the original case and at point B in other cases of slope with sand trench. Also, in the two cases of slope without or with sand trench, it can be found that points A and C have small affect with strip load. In the case of point B, the additional vertical displacements decrease as slope angle β decreases. In the case of slope angle $\beta = 45^o$, when the sand trench is at distance X = 0.0, the additional vertical displacements are approximately 0.25 of those obtained from original case, whereas, these values are approximately 0.31 and 0.36 in the case of slope angle $\beta = 30^o$ and 20^o, respectively.

When distance X ≥ 2.0 m, the vertical displacements are approximately back to the original case, so, the effect of sand trench can be neglected.

Figure 12 shows the relationship between vertical displacement and slope angle β. It can be found that the vertical displacement increases as slope angle β increases, whereas, decreases as distance X of sand trench decreases. From this Figure it can be concluded that the sand trench has distance X = 0.0 is more affecting in vertical displacements than other positions.

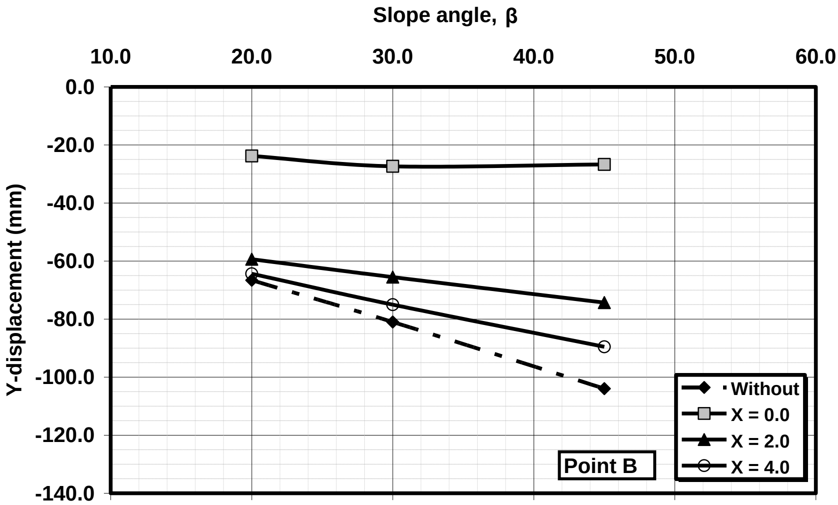


Figure 12. Vertical displacements versus slope angle β for point B due to strip footing, case of soft clay (C = 10 KN/m^2)

4.3. Displacements (cases of different types of clay)

From previous analysis and discussion, it can be found that the original soil profile without sand trench and case of sand trench has distance X = 0.0 represent the critical cases of study. So, these cases will be repeated with different soil profiles such as medium and stiff clay. The additional horizontal and vertical displacements were plotted in the Figures from 13 to 22.

a) Horizontal displacements

Figures 13, 14, and 15 show comparisons between additional horizontal displacements due to strip load for different types of clay soil, where, two cases of study, original clay soil without and with sand trench, have been studied. These Figures represent three slopes have angles of inclination β equal to 45^o, 30^o, and 20^o, respectively. Each Figure includes three points **A, B,** and **C,** where**,** each point represents two study cases. It can be shown that, in the case of soil profile with sand trench, the additional horizontal displacements are less than those obtained from case of soil profile without sand trench (original case), where give approximately 20% to 35% of the results obtained from original case. It can be noticed that the additional horizontal displacements in the case of slope angle β = 45^o are more than those values obtained in other slopes. Also, point **C** is more affected than other points, then point **B**, after that point **A**. It is clear that soft clay gives additional horizontal displacements more that those obtained from other types of clay soil. It can be found that, in the same case of study, the additional horizontal displacements at point **A** are approximately the same for the three different types of clay soil. In the case of slope angles $\beta = 30^o$ and 20^o, at the same point, the additional horizontal displacements are approximately the same, so that the difference can be neglected. This means that by decreasing the slope angle to be $\leq 30^o$, the additional horizontal displacements due to strip load are not affected.

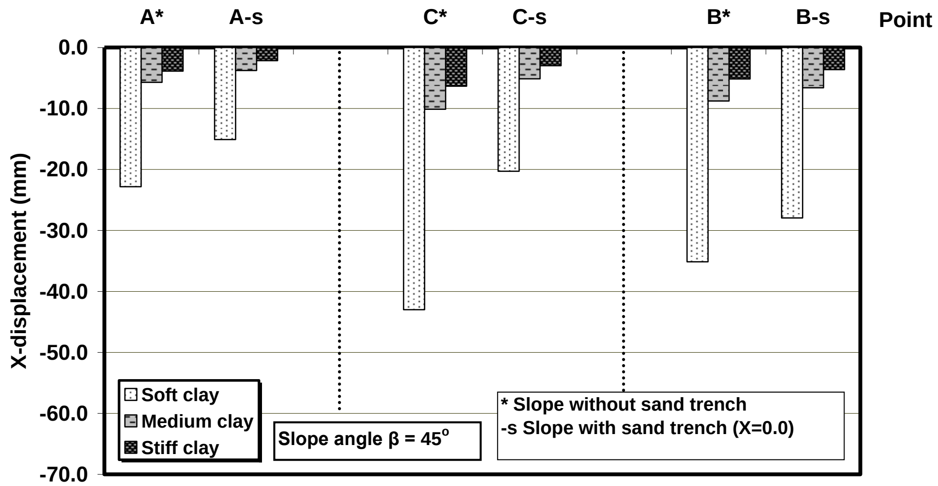


Figure 13. Comparison between additional horizontal displacements in slope ($\beta = 45^o$) for different types of clay soil due to strip load.

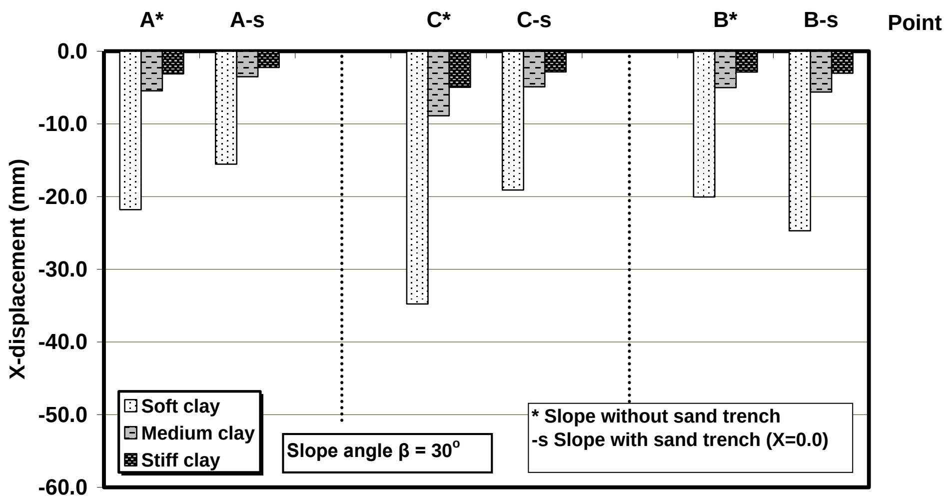


Figure 14. Comparison between additional horizontal displacements in slope ($\beta = 30^o$) for different types of clay soil due to strip load.

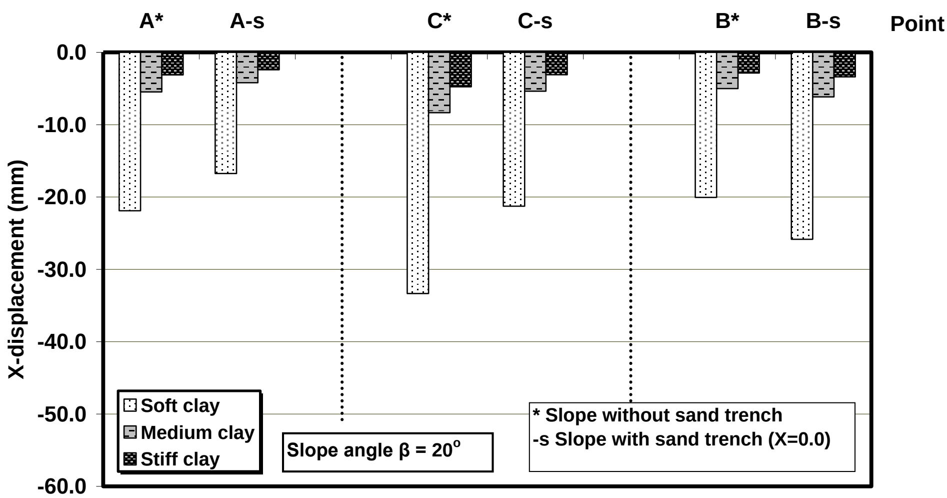


Figure 15. Comparison between additional horizontal displacements in slope (β = 20°) for different types of clay soil due to strip load.

Figures 16 and 17 show the relationship between the additional horizontal displacements at point **B** due to strip load and the cohesions of clay soil for different types of slopes and two cases of soil profiles without and with sand trench. From these Figures, it can be found that the additional horizontal displacement decreases as cohesion increases. Also, it can be noticed that, in the case of soil profile without sand trench, when the angle of slope $\beta \leq 30^o$**,** the additional horizontal displacements due to strip load are not affected as shown in Figure 16.

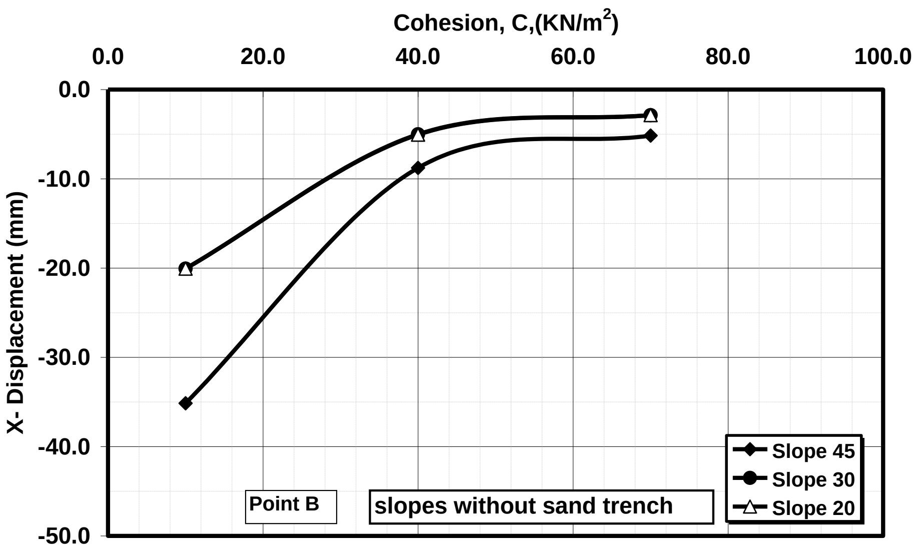


Figure 16. Additional horizontal displacements versus cohesion at point **B** for different slopes in the case of soil profiles without sand trench.

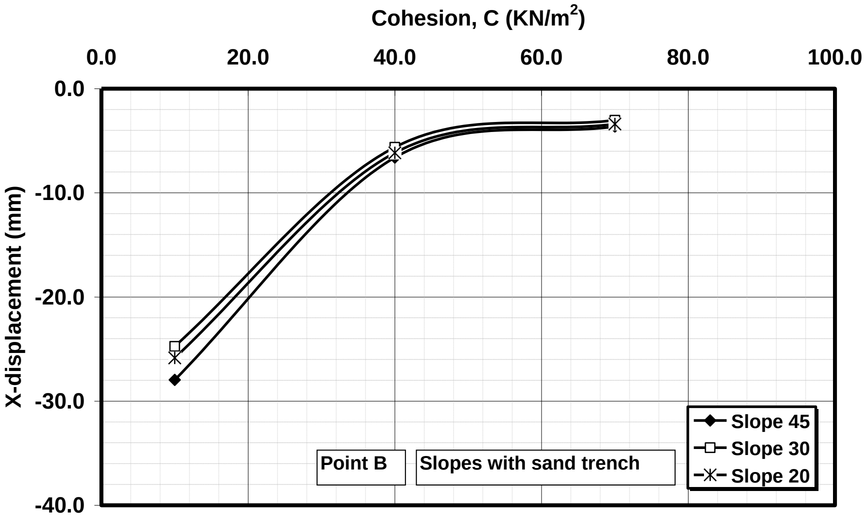


Figure 17. Additional horizontal displacements versus cohesions at point **B** for different slopes in the case of soil profiles with sand trench (X = 0.0).

From these Figures, in the case of soil profile with sand trench, it can be found that the additional horizontal displacement decreases as cohesion increases and the change in displacement due to change in slope angle is very small so that it can be neglected. This means that, in this case of slopes with sand trench, the additional horizontal displacement due to strip load does not affect by changing in slope angle β, especially, for high values of cohesion (medium or stiff clay).

b) Vertical displacements

Figures 18, 19, and 20 show comparisons between additional vertical displacements due to strip load for different types of clay soil, where, two cases of study, original clay soil without and with sand trench, have been studied. These Figures represent three slopes have angles of inclination β equal to 45^o, 30^o, and 20^o, respectively. Each Figure includes three points **A, B,** and **C,** where**,** each point represents two mentioned study cases. It can be shown that, in the case of soil profile with sand trench, the additional vertical displacements at point **B** are less than those obtained from other case of soil profile without sand trench (original case), where give approximately 25% of the results obtained from original case. Also, It can be noticed that the additional vertical displacements in the case of slope angle β = 45^o are more than those values obtained in other slopes. Also, point **B** is more affected than other points, then point **C**, after that point A which has upward displacements. It is clear that soft clay gives vertical displacements more that those obtained from other types of clay soil. From these Figures, it can be concluded that point **B** represents the critical point of study. It can be found that, In the case of slope angles β = 45^o, point **C** has downward displacement, then, it has upward displacement for slope angles β = 30^o and 20^o. It is obvious that, for point **B,** the additional vertical displacements decrease as slope angle β decreases, whereas, for points **A** and **C**, these values of displacement increase as slope angle β decreases as shown in point **A,** or change from downward to upward as shown in point **C**.

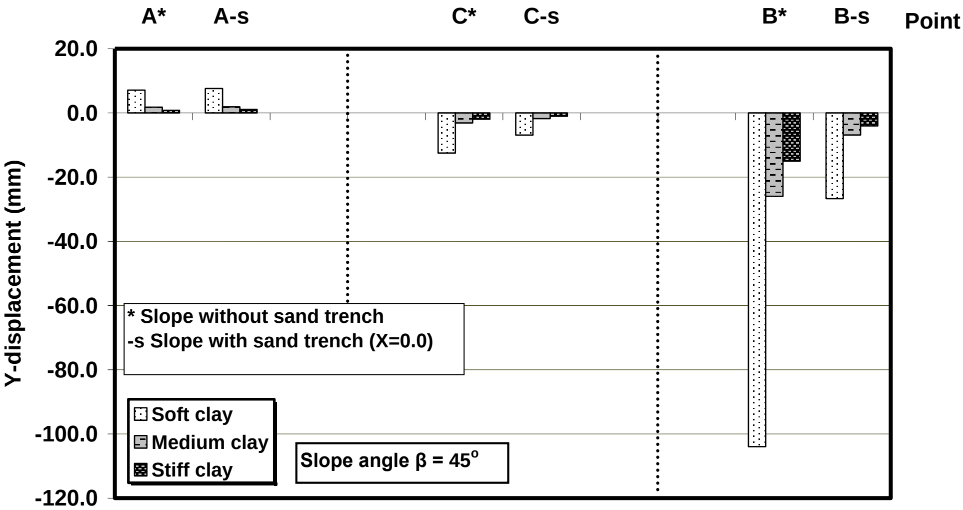


Figure 18. Comparison between additional vertical displacements in slope (β = 45°) for different types of clay soil due to strip load.

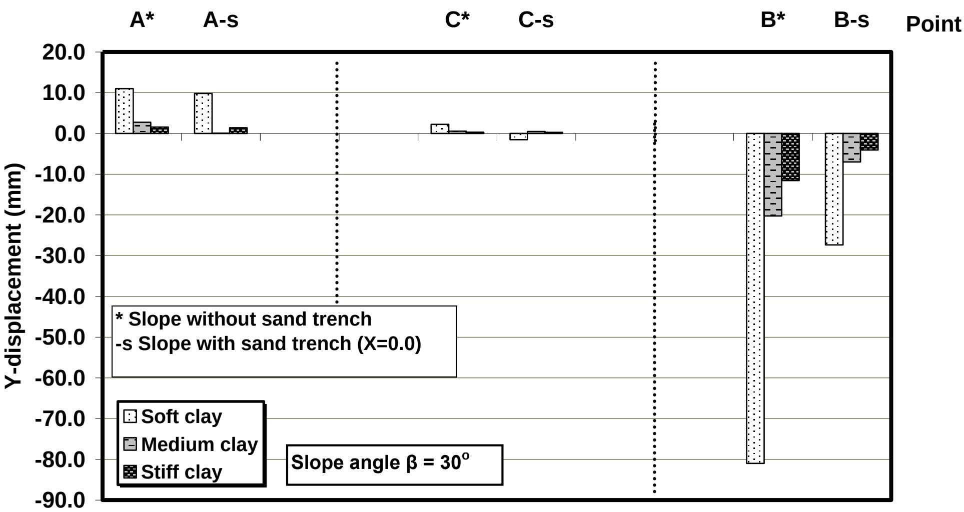


Figure 19. Comparison between additional vertical displacements in slope (β = 30°) for different types of clay soil due to strip load.

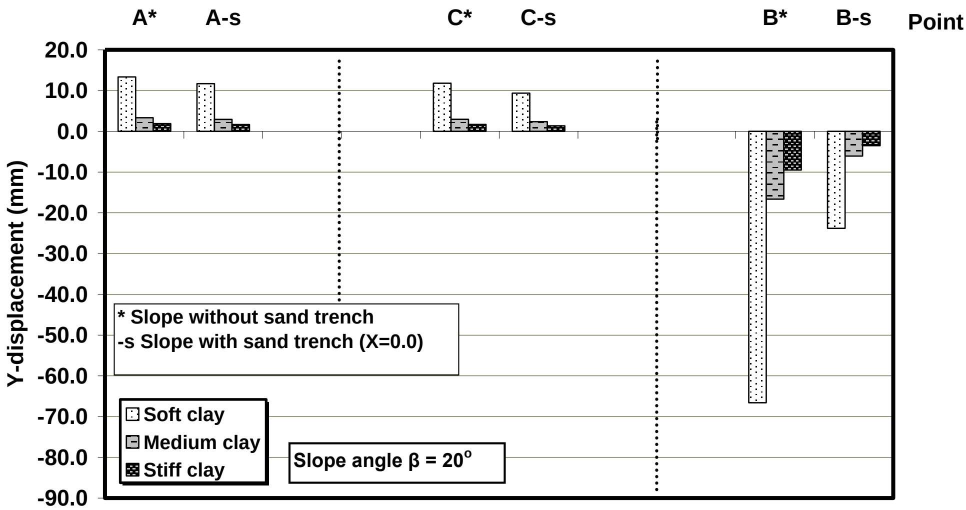


Figure 20. Comparison between additional vertical displacements in slope ($\beta = 20^{o}$) for different types of clay soil due to strip load.

Figures 21 and 22 show the relationship between the additional vertical displacements at point **B** due to strip load and the cohesions of clay soil for different values of slope angles and two cases of soil profiles without and with sand trench. From these Figures, it can be found that the additional vertical displacement decreases as cohesion increases. Also, in the case of soil profile without sand trench, these values decreases as slope angle β decreases as shown in Figure 21, whereas, the same thing in the case of soil profile with sand trench but the range of change is small as shown in Figure 22.

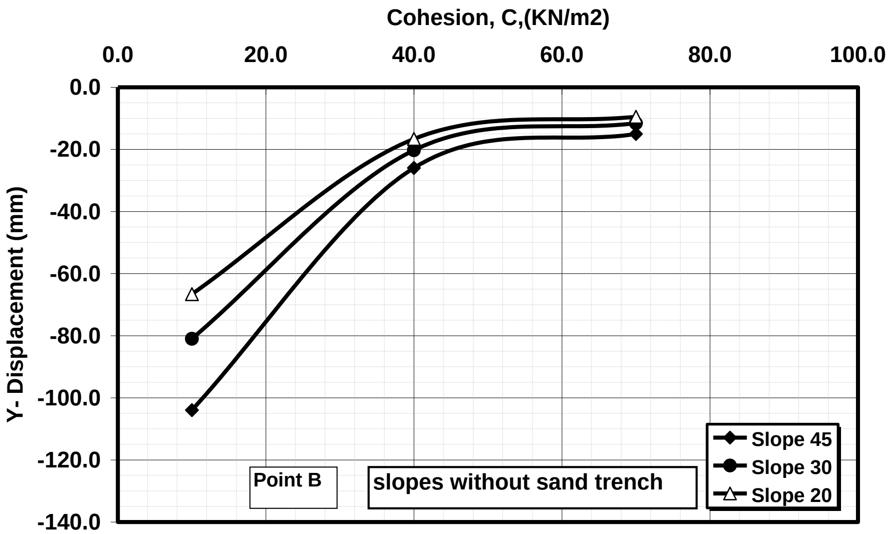


Figure 21. Additional vertical displacements versus cohesions at point **B** for different slopes in the case of soil profiles without sand trench.

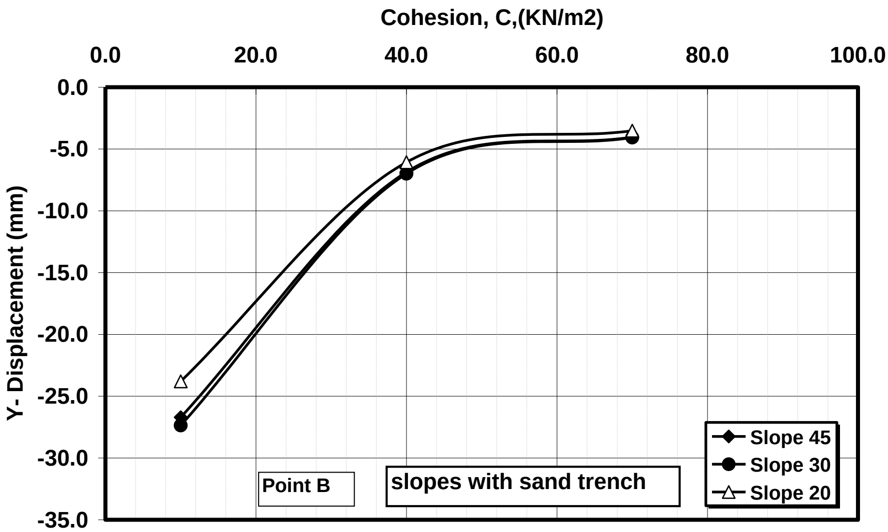


Figure 22. Additional vertical displacements versus cohesions at point **B** for different slopes in the case of soil profiles with sand trench (X = 0.0).

4.4. Effect of water content

In the present study, all previous study cases have been resolved using case of wet soil instead of dry soil. We found that the results did not change because the present study concerns with the additional displacements due to strip load only and neglects the initial displacements due to overburden pressure

5. CONCLUSIONS

The present study is concerned with the behavior of stabilizing slopes with sand trench in cohesive soil under the effect of strip footing. In this study, the main parameters were taken into consideration are slope angle (β), position of sand trench (distance X), and type of clay soil (cohesion C). The results obtained from this study were compared with the initial values obtained from case of soil profile without sand trench.

Based on the presented discussion and analysis of obtained results, the following main conclusions are noted:

1) The additional deformations in the case of soil profile without sand trench are more than those in the case of soil with sand trench and decrease as slope angles β decrease.
2) The effect of sand trench can be neglected when distance $X \geq 2.0$ m, where the results approximately return to the case of soil profile without sand trench.
3) In the case of additional horizontal displacement, the midpoint **C** is more affected with existing sand trench than other points. This means that point **C** represents the critical point of study.

4) In the case of additional vertical displacement, the top point **B** is more affected with existing sand trench than other points. This means that point **B** represents the critical point of study.
5) The additional vertical displacements decrease with existing sand trench and affect with sand trench position where decrease as distance X decreases.
6) In the case of point B, the additional vertical displacements decrease as slope angle β decreases.
7) In the case of slope angle $\beta = 45^o$, when the sand trench is at distance X = 0.0, the additional vertical displacements are approximately 0.25 of those obtained from original case without sand trench, whereas, these values are approximately 0.31 and 0.36 in the case of slope angle $\beta = 30^o$ and 20^o, respectively.
8) When the position of sand trench at distance $X \geq 2.0$ m, the vertical displacements are approximately back to the original case, so, the effect of sand trench can be neglected.
9) The position of sand trench at distance X = 0.0 is more affecting in vertical displacements than other positions. This means this position represents the critical case of study.
10) The additional horizontal and vertical displacements decrease as cohesion increases, and the effect of sand trench is more in the case of soft clay than other types of clay.
11) In the case of slopes with sand trench, the additional horizontal displacement due to strip load does not approximately affect by changing in slope angle β, especially, for high values of cohesion (medium or stiff clay).
12) The final conclusion is that the existing of sand trench at distance X = 0.0 improves the behavior of stabilizing slopes in clay soil.

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سلوك الميول فى التربة المتماسكة والمحتوية على خندق من الرمل تحت تأثير أساس شريطى

نظراً لأن الميل فى التربة المتماسكة خصوصاً الطينية منها من الموضوعات الهامة في مجال الهندسة المدنية. وكثيراً ما تحدث إنهيارات لهذه الميول نتيجة تأثير الأحمال المختلفة مثل وزنها أو حركة المركبات أو الأساسات الشريطية أو الأحمال الديناميكية.

تعتبر دراسة الميول من الموضوعات التى تهم المهندسين الإنشائيين ومهندسى التخطيط ونظراً لوجود هذه الميول أحياناً ملاصقة للحوائط الساندة مما قد ينتج عنها بعض المشاكل الناتجة من التشكلات والأزاحات الزائدة خصوصاً في التربة الطينية اللينة والمتوسطة التماسك والمتماسكة ولذلك كان من الواجب البحث عن طريقة لتحسين سلوك الطين و تقليل اللأزاحات به و الناتجة من الأحمال الشريطية.

فى هذا البحث تم دراسة تأثير بعض المتغيرات على سلوك الميول تحت تأثير الأحمال الشريطية منها زاوية الميل والمسافة الأفقية (X) بين الخندق الرملى و الحافة العلوية للميل وكذلك التماسك للتربة الطينية (C). هذا و قد تم دراسة ثلاث ميول ذات زوايا 45 و30 و 20 درجة و تم أخذ ثلاث مواضع مختلفة للخندق الرملى طبقاً للمسافة الأفقية (X) منها واحده عند الحافة العليا للميل وأثنين داخل الميل نفسه. أيضاً تم دراسة ثلاث أنواع من التربة الطينية و هى الطين اللين (Soft clay) والمتوسط التماسك(Medium clay) والمتماسك(Stiff clay).

هذا وقد تم تحديد عدد من النقاط الحرجة على خط الميل وهى عند أسفل ومنتصف وقمة الميل ودراسة الأزاحات الناتجة فيها من الحمل الشريطى ومن تأثير المتغيرات السابقة وقد وجد أنه نتيجة تأثير المتغيرات المدروسة فإن قيم الأزاحات تقل في وجود الخندق الرملى الملاصق لحافة الميل العلوية لتصل الى حالى 25% من القيم فى حالة عم وجوده و خصوصاً فى زوايا الميول الكبيرة. ومن الأستنتاجات الهامة لهذه الدراسة وهى أن تأثير الخندق الرملى يظهر بوضوح فى حالة الطين الين. وأيضاً أظهرت هذه الدراسة أن وجود الخندق الرملى يحسن من سلوك الميل المقام فى التربة الطينية اللينة (Soft clay).