https://erjm.journals.ekb.eg
ISSN: 1110-1180

DOI: ---------

ERJ
Engineering Research Journal
Faculty of Engineering
Menoufia University

A Numerical Study of an Irrigation Canal Constructed on Expansive Soils

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ABSTRACT

Irrigation and drainage trapezoidal hydraulic canals constructed on unsaturated expansive soils are susceptible to cracking and uplift due to water content variations in expansive soil. Canal lining and rehabilitation project aim to reduce swelling of expansive soil, distribute water, reduce losses, and to ensure the water reaches the ends of the canals. Expansive soils in Egypt are found in several areas, such as Aswan, Assiut, Edfu, New Cairo, Madinat-Nasr, Alshrouk City and the New Valley. In the present study, expansive soil has been investigated under the lower Al-kharit irrigation canal in Aswan Governorate, Egypt, using field observations and numerical modeling. The numerical model is performed using SIGMA/W 2007 software, which is part of the Geo-Studio software package, to simulate the irrigation canal constructed on expansive soil. The results of analysis showed that the effect of canal rehabilitation can reduce the heave of expansive soil and increase the slope stability of irrigation canal. Additionally, a comparison of two engineering programs PLAXIS-GeoStudio gives acceptable accuracy of using numerical model that use independent solutions or field measurements. It is studied the effect of thickness of the rehabilitated layer with cobbles through a series of simulations to determine the safe design and minimum cost.

Keywords: *canal rehabilitation; expansive soil; lower Al-kharit canal; numerical model.*

1. Introduction

Egypt faces water shortages due to rapidly growing population, industrial needs and losses of irrigation canals so it should improve the performance of irrigation systems[1]. Rehabilitation of Irrigation Canals has become essential to reduce the seepage losses of water from irrigation canals[2]. These losses of water from canals can be reduced to 60-80%[3]. The rehabilitation of irrigation canal had an important effect on the livelihood of rural people. It is noticed that the significant increase in number of days worked by agricultural labor and the wages also increase[4]. Rehabilitation involves the restoration or reconstruction of irrigation and drainage facilities to their original design. It can also include the extension of service areas and the saving of additional structures such as service roads, drainage systems and flow control structures. Rehabilitation is typically undertaken to improve the efficiency of irrigation and drainage systems, and to extend their lifespan[5]. Rehabilitation of Irrigation Canals can Distribute and reach water to the ends of the canals[6]. Egypt is one of the countries that have started using this technique.

The construction of irrigation canals on expensive soils is necessary, and proper techniques should be followed in order to minimize the damage. Because the repair and rehabilitation of damaged structures imposes significant financial burdens on the project[7]. As the moisture content in water increases, a swelling soil generates heave and swelling pressure, which are both problematic[8]. Some clay minerals swell when they absorb moisture. This increases the distance between the particles, which distorts the internal stress equilibrium[9]. Even expansive soil may never swell if its moisture content remains constant. However, this rarely happens because moisture content changes for many reasons[10]. These reasons can be summarized as follows [11-14]:

- Rain fall and rise in the ground water table.
- Reducing load increases the swell of soil.
- Transition of moisture with time; moisture transition through soil is slow and requires weeks and even years to saturation of soil depending on the permeability and thickness of layer of expansive soil.

- Dry density, dense clays will expand more than the same clay at lower density with the same moisture content.
- Mineral type and amount, soils containing a considerable amount of montmorillonite minerals will appear high swelling and shrinkage characteristics

Transpiration; the roots of trees can extract quantities of water from surrounding soil which increase the swell and shrink of soil. Technical references suggest several methods to control or prevent clay swelling in engineering projects. Lime is one of the most effective materials for stabilizing clay, reducing swelling and improving the mechanical properties of expansive soils. This change in clay behavior occurs when the sodium in the soil is replaced by the calcium in lime[15,16]. Also, replacement soil is an effective way to reduce the effective thickness of expansive clays, as evidenced by local experience. Few researchers have shown results from numerical analyses to sure this approach[17].

The main objective of this work is to study the effect of the lower Al-kharit Canal project constructed on expansive soil on swelling behavior. The lower Al-kharit Canal is located within the national project for the lining and rehabilitation canals. A part of the canal was selected to conduct the numerical modeling. The effect of canal rehabilitation was also studied with rehabilitated layer (by cobbles) to reduce the soil swelling effects on the canal. To investigate the performance of this rehabilitated layer, soil swelling and relative displacement of canal section panels are measured by recording of surveying points.

2. Site Investigation

The lower Al-kharid canal branches from the toshka canal, in front of Regulator at km 6.500. The canal serves total area of (2902) fed. The discharge of the canal ranges from 145,000 to 204,000 cubic m per day. The lower Al-kharit Canal feeds two canals. The station of sucking of the upper Al-Kharit canal, which takes water on the right side at 2.90 km and extends 1.176 km to serve (1349) fed and the Branch 114 of Alkharit canal, which takes water on the left side at 12.600 km and extends 3.800 km to serve (3680) fed. Figure (1) shows the location of the region of the lower Al-kharit Canal, a graph cross-section, changes along the canal and the hydraulic design. The design data of the canal is shown in Table 1. The canal lies within the northeastern area between 24° 25' 27.52" N, 24° 28' 33.42" N, 33° 4' 1.89" E and 33° 8' 47.91" E. Extensive geotechnical studies have been done to evaluate soil swelling behaviour in the path of the lower Al-kharit canal project. These studies include field investigation, sampling (33boreholes), and laboratory tests. The soil samples in most cases are clay soils, based on a unified classification method (USCS). These samples were obtained from the canal (bank level), about every 250 m along 6.200 km length of the canal path (from 4.800km to 11.000km) as shown in figure 1-b. The results show that the plasticity index (PI) of samples varies from 0 to 31%.

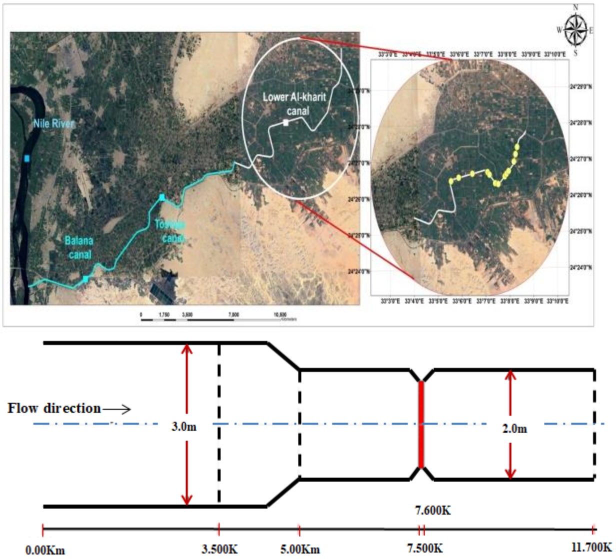


Figure 1- (a) The location of the Lower Al-kharit canal; (b) The location of boreholes (samples)
(c) The geological profile along Al-kharit canal.

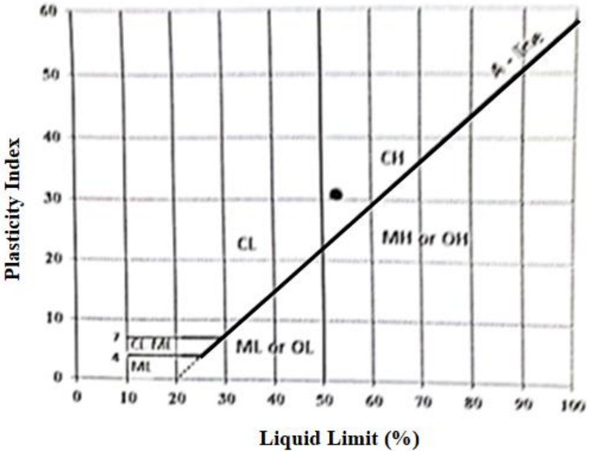
Table 1- The design data of the lower Al-kharit canal

canal	from	To	Bed Width (m)	Slide Slope
The lower Al-kharit canal	Intake	2.900	3.0	1:1.5
	2.900	5.000	3.0	1:1.5
	5.000	7.500	2.0	1:1.5
	7.500	7.600	Covering 2pipe (m 0.80)	
	7.600	11.700	2.0	1:1.5

It is inferred from these results that expansive soil behavior should be studied in all the length of the lower Al-kharit canal path. As discussed, the mechanical characteristics of bed soil are not constant in all canal paths. The result of free expansion ratio, unconfined compressive strength (q_{ult}) and Atterberg limits tests for samples, obtained from 4.800km to 11.00km of this canal, are represented in figure (2) and table (2) respectively. The maximum values are obtained as input parameters of numerical modeling at kilometer 9.300 of this zone. The ground water table (GWT) is located at a depth of 1m from the land surface (bank level). This water seeps into the soil around the irrigation canal and changes its moisture. The physical and mechanical parameters of the expansive soil are given in Table (3).

Table 2- Location of samples from km 4.800 to km 11.00

Km	q_{ult} (kg/cm2)	L.L (%)	P.L (%)	P.I (%)	Free expansion ratio(%)
4.800	0.34	48	21	27	58
5.400	3.22	52	24	28	72
6.400	0.79	52	22	30	65
7.500	0.94	51	24	27	60
7.700	2.97	52	24	28	74
8.300	3.24	53	23	30	65
8.500	0.47	51	24	27	54
9.100	0.43	49	25	24	58
9.300	2.98	53	22	31	78
9.500	3.24	53	23	30	70
10.100	0.42	46	23	23	64
10.500	3.39	51	24	27	70
.900	0.91	51	23	28	60



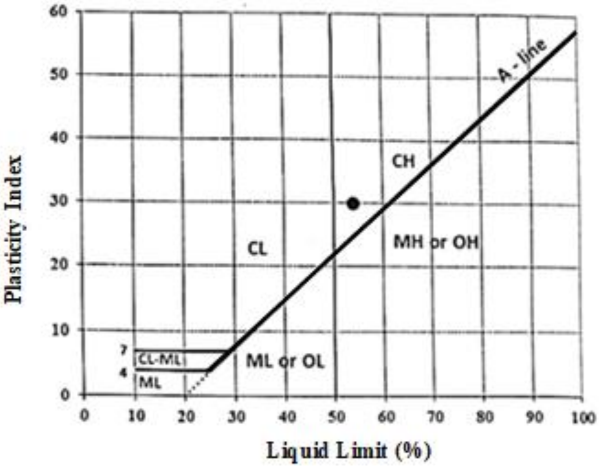


Figure 2- Atterberg limits for canal at kilometer 9.300 (a) From dpth 0 to 5m (b) From depth 5 to 15m

Table 3- The properties of soil

Soil properties	Expansive soil
Total unit weight γ/(kN m^{-3})	17.27
Specific gravity (G_s)	2.62
Initial void ratio (e_0)	0.65
Saturated elastic modulus for the soil E_{sat}/(kPa)	1071
Saturated coefficient of permeability K_{sat}/(m/day)	0.00523
Volumetric water content at saturation (Θ_s)	0.5015
Cohesion (C) kPa	20
Angle of friction (φ)	20°
Soil properties	Stiff clay
Total unit weight γ/(kN m^{-3})	19
Saturated elastic modulus for the soil E_{sat}/(kPa)	50000
Passion Ratio	0.30

3. Methodology

In this paper, the GeoStudio (GEO-SLOPE International Ltd, 2007) software is used to simulate the numerical model. SIGMA/W software is considered as a one of the software programs in the Geo-Studio software package which is used for stress-deformation analysis of earth structures. The stress deformation process is simulated by Finite element based software SIGMA/W as products of the

GeoStudio package which is used to solve problem using a fully coupled option. The change in pore pressure and its distribution in a soil mass due to external loading can be computed using coupled formulation. This software which used to model unsaturated expansive soils is based on the behavioral model and equations proposed by[18].The commercial software SIGMA/ combined the hydraulic analysis code in SEEP/W (GeoSlope 2007b) with the static equilibrium analysis to realize the coupled analysis. For unsaturated soils two stress state variables, namely, net normal stress and suction, need to be considered independently to adequately describe the mechanical behavior of unsaturated soils[19]. Based on this two stress state variables concept, proposed a semi-empirical model was predicted the unsaturated soil shear strength(τ_f) using SWCC as a tool[20].

$$\tau_f = C' + (\sigma - u_a)\tan\emptyset' + (u_a - u_w)[\left(\frac{\theta_w-\theta_r}{\theta_s-\theta_r}\right)\tan\emptyset']$$

(Equation 1)

Where:

σ-ua is net normal stress, u_a–u_w is suction, θ_w is volumetric water content, θ_s is saturated volumetric water content, and θ_r is residual volumetric water content. θ_s and θ_r can be obtained from the SWCC using the construction method without using any other fitting parameters.

The soil–water characteristic curve (SWCC) explains the degree of saturation corresponding to a particular suction in soil and becomes a dominant relationship to understand the unsaturated soil behavior. The hydrostatic variation of PWP along vertical distance with reference to the ground water table is formed to make the initial suction condition within the surficial range from around 200 to 300 kpa [21]. The volumetric water content function and hydraulic conductivity function are calculated based on information provided by[22, 23]. The volumetric water content function for probable negative pressures can be calculated by [22] formed method. This method is shown by the following equations: -

$$\theta_w = C_\Psi \frac{\theta_s}{\{ln\left[e + \left(\frac{\Psi}{a}\right)^n\right]\}^m}$$

(Equation 2)

Where:

Θ_w is volumetric water content, C_Ψ is correction function introduced later, Θ_s is saturated volumetric water content, e is constant value (2.71828), Ψ is negative pore-water pressure, a, n, m : curve fitting parameters as shown in figure (3)

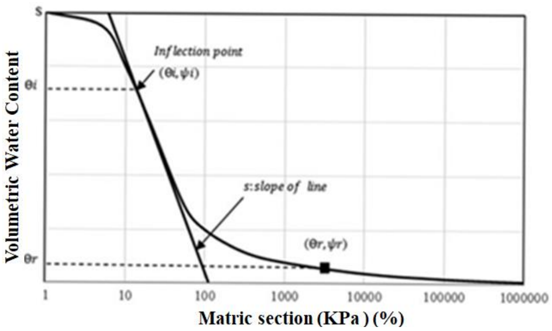


Figure 3- Sample plot for the graphical solution of the four parameters (a, n, m and Ψ).

It is studied the rehabilitation of lower Al-kharit canal on the expansive soil with cobbles. The thickness of rehabilitated layer with cobbles is ranged from 0.3 to 0.5 with different triangle of cobbles layer supported the slope of canal (width of this triangle (b) is ranged from 2m to 3m) as shown in figure (4). Three points (top point, sidewall point and bottom point) were selected to be the surveying points, as shown in figure (4).

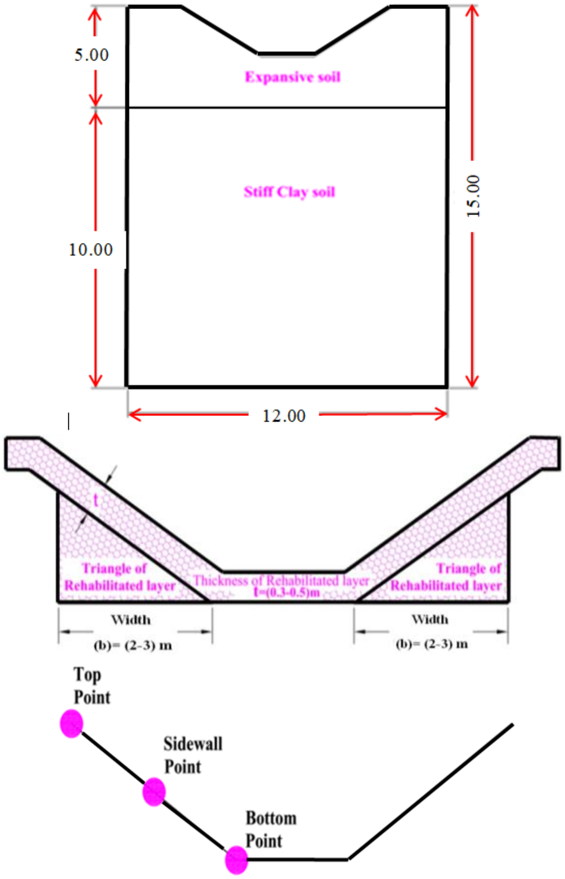


Figure 4- Dimension of cross section which used in the analysis (a) Before rehabilitation canal (b) With rehabilitated layer (c) Surveying point's location on canal section.

The initial stress field within the slope of the model is constructed by in situ analysis based on K_0 ($K_0=\mu/(1-\mu)$) where K_0 is the lateral earth pressure coefficient at rest and μ is the Poisson's ratio. Initial effective stress resulting from this analysis is shown in Figure (5). Generally, the matric suction in simulation is created using the software during period of days. The value of this suction is maintained equal to 400 kPa. This value of suction is achieved using the environmental soil moisture content[22,24]. Analysis is performed with transient soil program with automatic time increment.

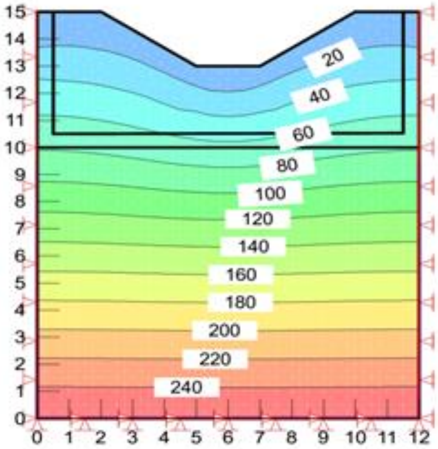


Figure 5- The Initial effective stress distribution (kPa) of expansive soil before rehabilitation.

To validate a model, the predictions of a numerical approach are compared to the results of engineering programs (SIGMA/W, Plaxis 2D). Volumetric strain is represented as heave in the vertical direction, as lateral displacements are prevented by the boundary conditions in the Plaxis model. The maximum volumetric strain of the expansive soil is set to 35%. The PLAXIS 2D program was validated according to Eq. (3), which was shown to be able to simulate the Volumetric strain of expansive soils (PLAIS 2D Reference Manual CONNECT Edition V20 tutorial[25].

$$\boldsymbol{\varepsilon_q} = \sqrt{\frac{2}{3}\left[\left(\varepsilon_{xx}-\frac{\varepsilon_v}{3}\right)^2+\left(\varepsilon_{xx}-\frac{\varepsilon_v}{3}\right)^2+\left(\varepsilon_{xx}-\frac{\varepsilon_v}{3}\right)^2+\frac{1}{2}+\left({\gamma_{xy}}^2+{\gamma_{xy}}^2+{\gamma_{xy}}^2\right)\right]}$$

(Equation 2)

Where:

ε_{xx}, ε_{yy}, ε_{zz}, are the individual Cartesian strain components, ε_v, is the volumetric strain, ε_q, is the deviatoric strain

4. Comparison

The purpose of comparsion exercises in simulation models is to ensure that the models are used correctly and that the model parameters, such as volumetric strain, are chosen with adjusted values. The comparison procedure has been conducted by achieving an acceptable comparison between the predicted heave of the soil that obtained by the comparison models (plaxis 2D and GeoStudio). The simulation of matric suction is carried out over period of 1800 days for canal before rehabilitation and 4000 days for canal after rehabilitation to reach steady state condition. Figure (6) illustrates the heave of surveying points before rehabilitation. Figure (7) shows the heave of the top point after rehabilitation with cobble thicknesses of 0.3 m and 0.5 m respectively.

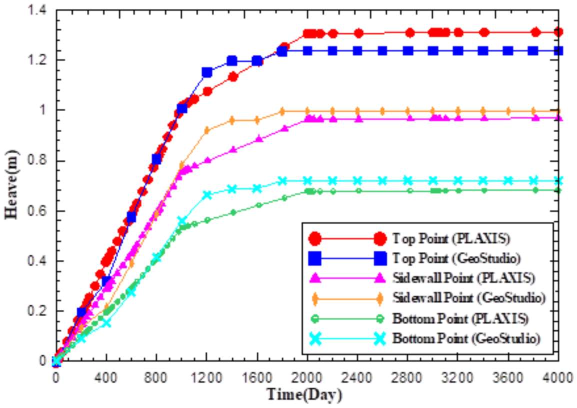
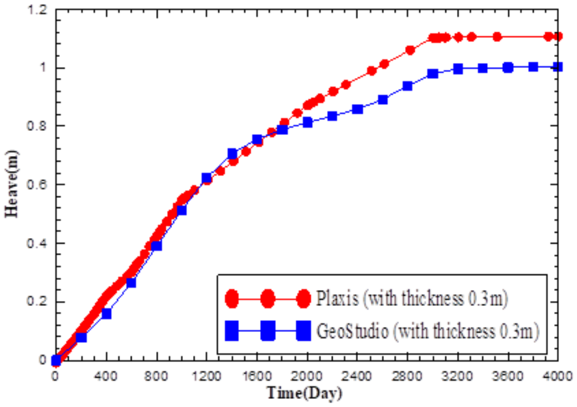


Figure 6- Comparison between PLAXIS and GeoStudio for canal before rehabilitation of surveying points.



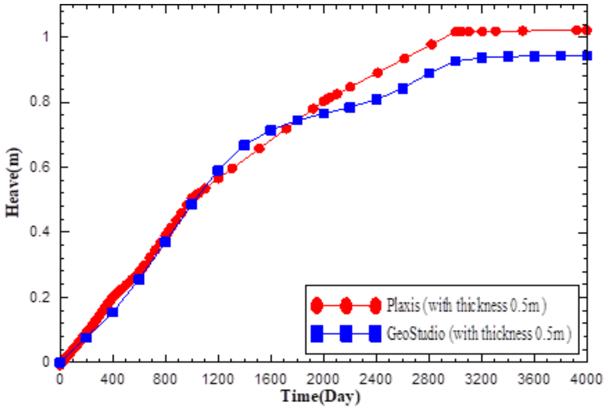


Figure 7- Results of the SIGMA/W comparison (Plaxis 2D) of expansive soil after rehabilitation canal for top point.

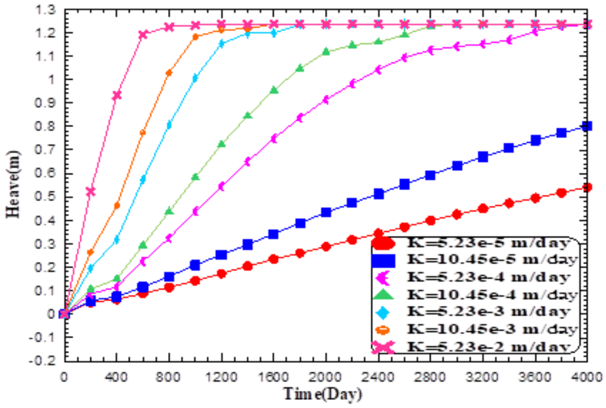
Figures (6) and (7) demonstrate that the heave calculated using engineering programs (SIGMA/W and Plaxis 2D) is almost identical, which confirms the eligibility of the SIGMA/W program to simulate the heave of expansive soil.

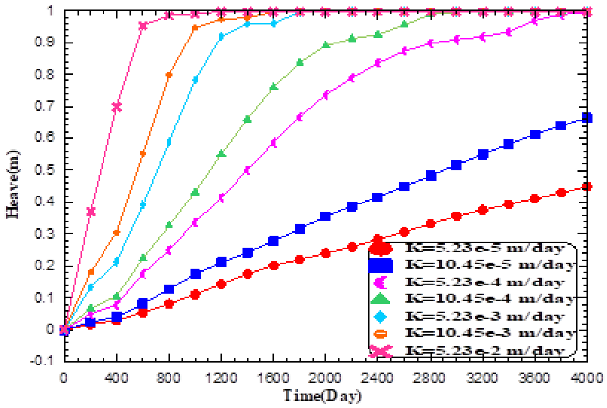
5. Results and Discussion

A parametric study was used to investigate the effect of the canal rehabilitation on the heave and slope stability of the canal.

5.1. The Effect of Permeability of Expansive Soil

This study investigated the effect of permeability coefficient (k) of expansive soil on the heave of irrigation canal before rehabilitation. Six cases were considered (i.e. assuming different coefficient of permeability values of the studied soil). Figure (8) illustrates the variation of calculated heave with respect to time for different coefficient of permeability values considered in this study of surveying points.





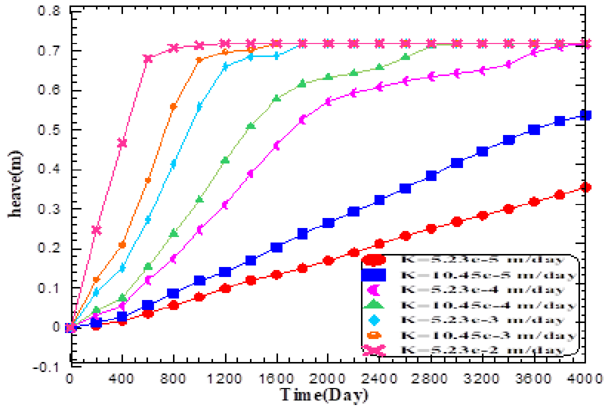


Figure 8- Variations of heave over time at different values of permeability coefficient of expansive soil at surveying points (a) Top point (b) Sidewall point (c) Bottom point.

When the saturated coefficient of permeability is less than 5.23×10^{-4} m/day, the heave needs more time to reach the steady state for three surveying points as shown in figure (8). By increasing the saturated coefficient of permeability to 5.23×10^{-4} m/day, the expansive soil needs about 4000 days to reach steady state. When the saturated coefficient of permeability is more than 5.23×10^{-4} m/day, the heave takes less time to reach the steady state.

5.2. The Effect of Thickness of Expansive Soil

The thickness of the expansive soil is very effective, whether it is directly below the irrigation canal. The effect of expansive soil thicknesses (H) under the irrigation canal before rehabilitation is studied as shown in figure (9). Figure (10) illustrates the variation in heave values at surveying points for different expansive soil thicknesses.

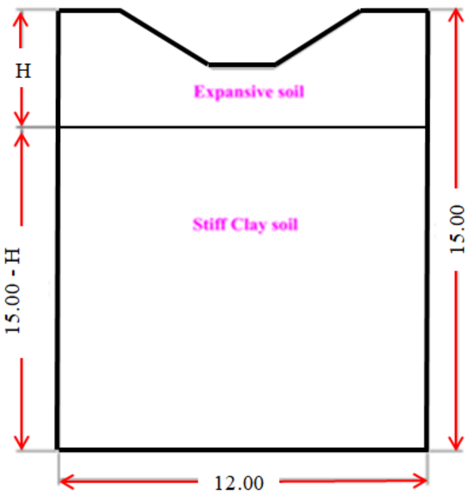
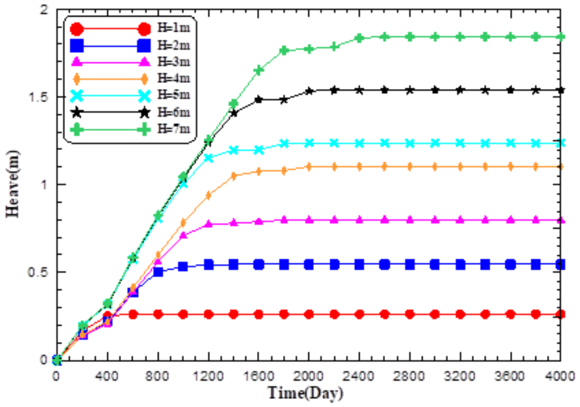
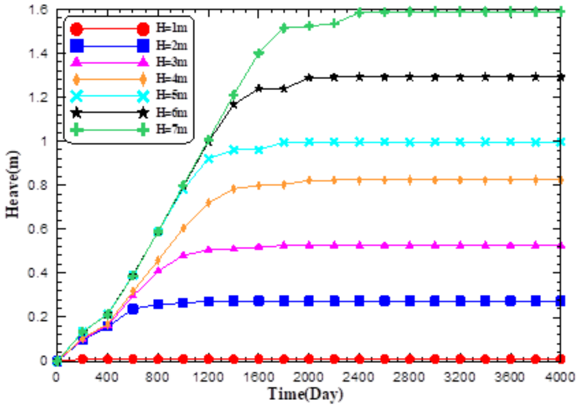


Figure 9- The change in thickness of expansive soil.





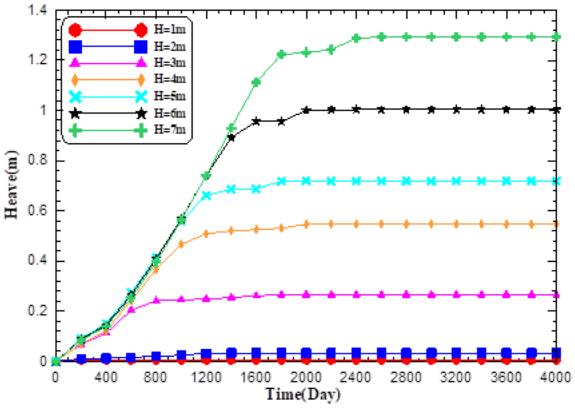


Figure 10- Variations of heave over time at different thicknesses of expansive soil at surveying points (a) Top point (b) Sidewall point (c) Bottom point.

It is noticed from figure (10) that the relative thickness of expansive soil (H/15m) is less than 6.667%, it has no effect of heave on the sidewall point. Similarly, when the relative thickness of expansive soil is less than 13.333%, it has no effect of heave on the bottom point. Note that when the thickness of the expansive soil increases, the heave increases.

5.3. The Effect of Canal Rehabilitation

Canal rehabilitation on expansive soil can be defined as adding a replacement layer over the excavated surface of the canal to minimize the swelling of expansive soil. A comparison between the canal behavior before and after rehabilitation is conducted to focus on the rehabilitation effect on soil heave. Figure (11), (12) and (13) show the heave of expansive soil at surveying points of irrigation canal before and after rehabilitation at steady state condition.

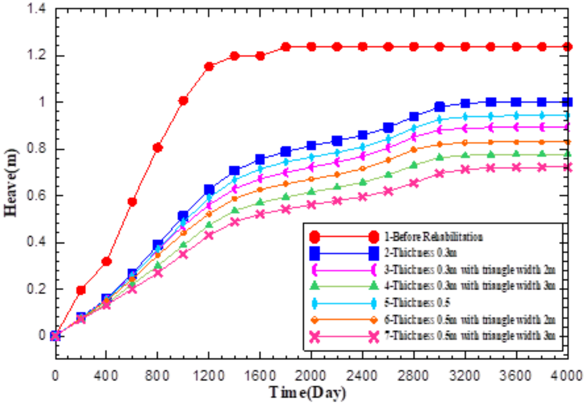


Figure 11- Variations of heave versus time before and after rehabilitation at top point.

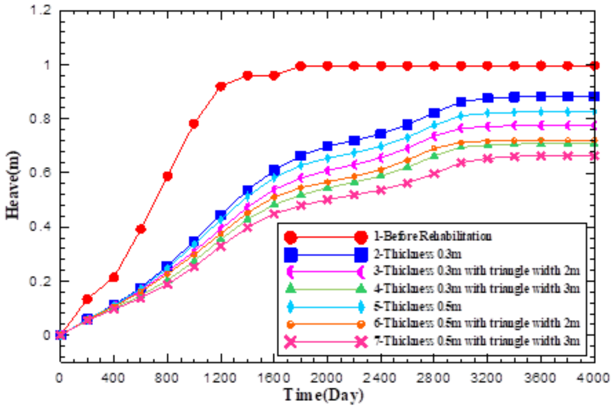


Figure 12- Variations of heave versus time before and after rehabilitation at sidewall point.

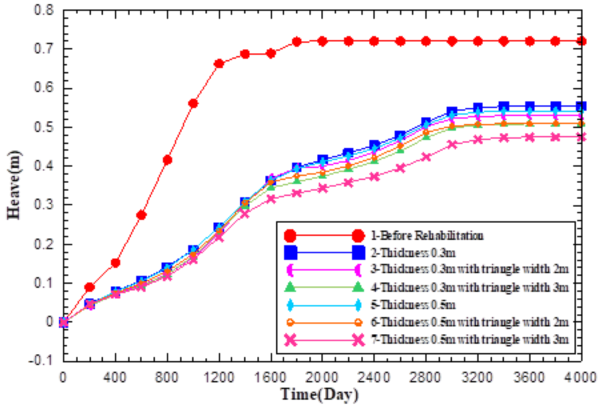


Figure 13- Variations of heave versus time before and after rehabilitation at Bottom point

Figure (11) shows that the heave at top point reach 1.23m before rehabilitation and is decreased by about 19%, 28%, 37%, 24%, 33% and 42% after rehabilitation of the canal (with cobbles) by 0.3m thickness, 0.3m thickness with triangle width = 2m, 0.3m thickness with triangle width = 3m, 0.5m thickness, 0.5m thickness with triangle width = 2m, and 0.5m thickness with triangle width = 3m respectively. Figure (12) shows that the heave at sidewall point of irrigation canal reach about 0.996m before rehabilitation and is decreased by about 12%, 22%, 28%, 17%, 29%, and 34% after canal rehabilitation (with cobbles) with thickness = 0.3m, thickness = 0.3m with triangle width = 2m, thickness = 0.3m with triangle width = 3m, with thickness = 0.5m, thickness = 0.5m with triangle width = 2m, and thickness = 0.5m with triangle width = 3m respectively. figure (13) shows that the heave at bottom point of irrigation canal reach 0.72m before rehabilitation and is decreased by about 24%, 26%, 29%, 25%, 29%, and 34% after canal rehabilitation (with cobbles) with 0.3m thickness, 0.3m thickness with triangle width = 2m, 0.3m thickness with triangle width = 3m, 0.5m thickness, 0.5m thickness with triangle width = 2m, and 0.5m thickness with triangle width = 3m respectively. From figures (11), (12), and (13), we observed that the steady state of the canal before rehabilitation is achieved more quickly than the steady state of the canal after rehabilitation. Also, the effect of canal rehabilitation on swelling reduction ratio (R) is studied.

$$R= [(S_o-S_i)/S_o] \times 100$$

{Where, R% swelling reduction ratio, S_o= maximum Heave of before rehabilitation and S_i = Heave after rehabilitation. Figure (14) shows the swell reduction ratio values (R %) of expansive after rehabilitation by using engineering programs (SIGMA/W and Plaxis 2D).

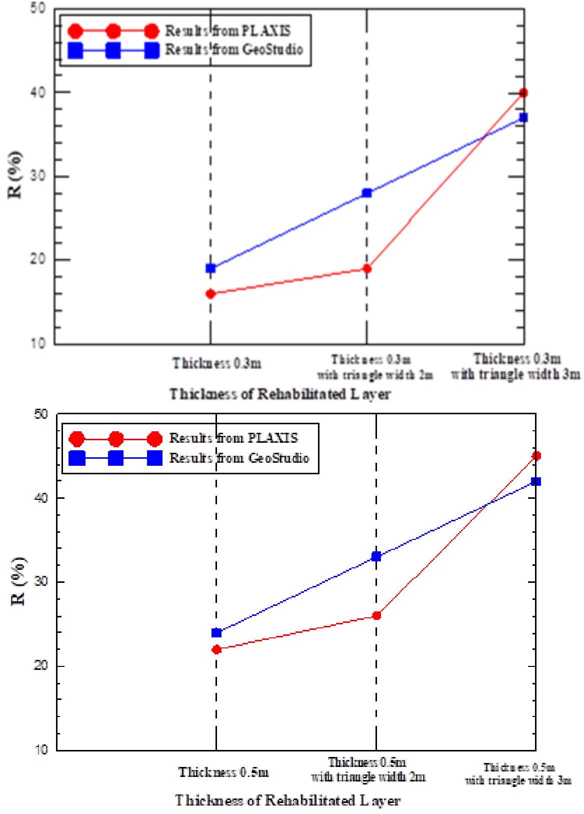


Figure 14- The swelling reduction ratio after rehabilitation canal.

5.3.1. Calculation of Slope Stability of Expansive Soil

The long-term stability of irrigation canal slopes is important to prevent soil sloughing under various operating conditions over the life of the canal. The canal should be stable if steady seepage from canal happens or even a rapid drawdown due to sudden unknown conditions occurs. The most critical conditions for the operation of the proposed canal are expected to occur when the canal water recedes rapidly (sudden rupture), potentially leaving residual pore water pressure on the side slope. SLOPE/W solves the two-factor safety equations; one equation satisfies force balance and the other satisfies moment balance. In order to calculate the factor of safety (FS) for a slope in terms of effective, the pore water pressure must be estimated [26].

There are many solutions for FS One-dimensional [27,28] two-dimensional and three-dimensional methods [29,30] use saturated and unsaturated conditions dimension slope. These methods can generally be divided into three categories: (i) limit equilibrium methods; (ii) finite element stress methods (FEM); (iii) finite element methods for strength reduction. Due to its long history and simplicity, the use of limit equilibrium methods seems to be the most popular (GeoSlope 2007c). Usually the stresses are analyzed in the limit equilibrium method and the static equilibrium conditions for the failure mass are extended according to some assumptions. However, limit equilibrium method does not always accurately represent the actual stress state in the ground. In contrast, FEM produces stresses that are more realistic and closer to actual soil conditions, especially if the static lateral earth pressure coefficient K_0 can be predicted (GeoSlope 2007c). Therefore, a finite element stress-based approach is more suitable for the problem involving expansive soil, because the stress state inside expansive soil is constantly changing with their volume. The factor of safety (FS) is a measure of the slope's stability, calculated by dividing the soil shear strength (τf) by the slope shear stress (τ). A higher FS indicates a more stable slope [21].

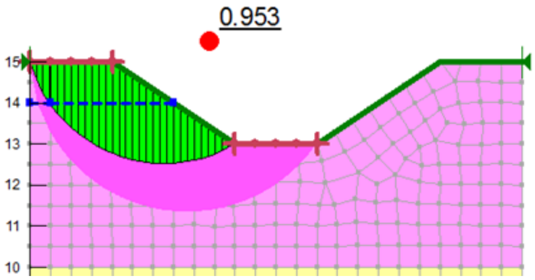
$$FS = \frac{Shear\ strength\ of\ soil\ at\ point\ (\tau_f)}{Shear\ Stress\ at\ this\ point\ along\ the\ slip\ surface(\tau)}$$

$$= \frac{\int_0^l \tau_f\, dl}{\int_0^l \tau\, dl}$$

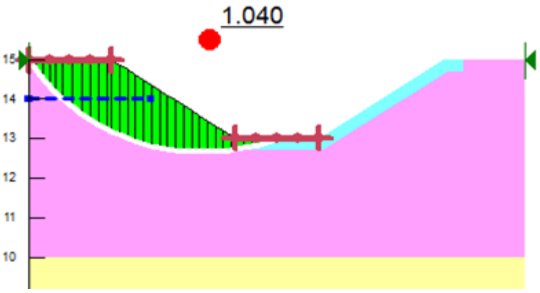
For saturated soil, the Mohr-Coulomb failure criterion is a well-accepted condition for determining shear strength in slope stability analysis. All runs were conducted with the piezemetric lines with Ru and a zero seismic coefficient [26]. The net normal stress, suction or PWP and volumetric water content along the sliding surface can be interpolated from the stress field and seepage field obtained from a coupled finite element hydrodynamic analysis of the slope section. Therefore, a complete finite element method for solving slopes with underground water conditions consists of the following steps: (i) coupling a hydrodynamic finite element analysis of the slope base with water seepage; (ii) Calculate the total or global FS. Usually the swelling values were recorded 12 and 18 days after impounding of the irrigation canal for construction, therefore, the numerical analyses were also done for 18 days[7]. SLOPE/W can effectively analyze slopes with different slip surface shapes, soil properties and ground water table conditions. The effect of a distributed surcharge (q) on the stability of a slope is studied in terms of the factor of safety. The distribution of weight along the slope and the loading at the top of the slope can have a significant impact on the stability[31]. The value of applied surcharge at the top of the slope is equal to 10kPa representing the live load of vehicles as the traffic loads are low in the area of study.

5.3.2. The Effect of Rehabilitation Canal on Slope Stability

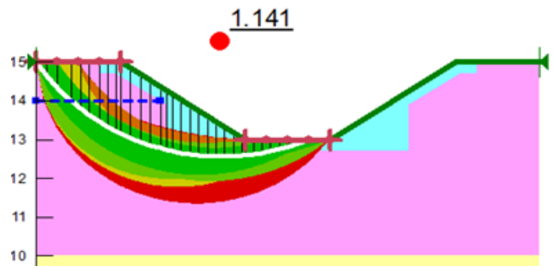
Water seepage into the slope soil increases its volume, especially the surface soil, which changes the stress distribution. The suction effect of the soil decreases as the water content increases. A hydrodynamic model is used to simulate stress changes and suction drops with slope profiles over time. After each time interval, the output information of the hydrodynamic model is used to calculate the factor of safety (FS) using a stress-based finite element model. This allows us to determine how FS varies due to water infiltration into the soil. As water seeps into the soil, FS gradually and slowly decreases[21]. The values of FS of canal before and after rehabilitation are shown in figure (15).



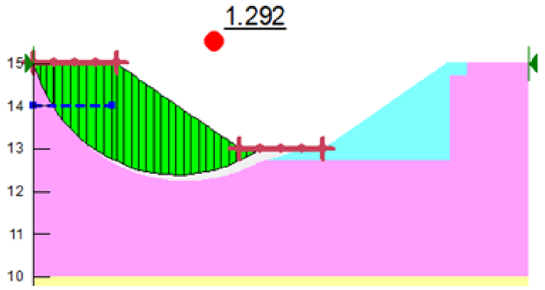
1- Before Rehabilitation



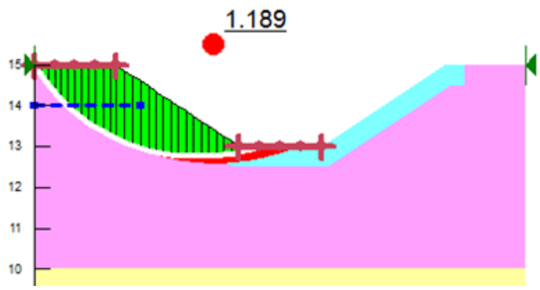
2- After Rehabilitation (thickness 0.3m)



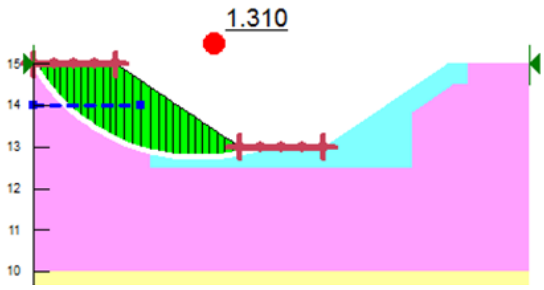
3- After Rehabilitation (thickness - 0.3m with triangle width 2m)



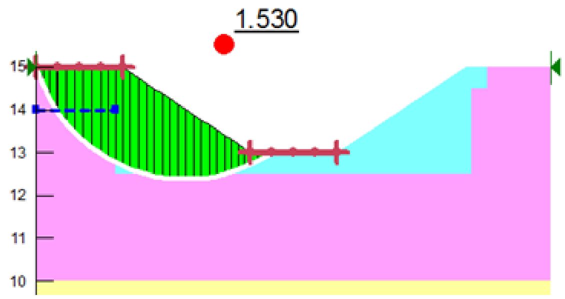
4- After Rehabilitation (thickness 0.3m with triangle width 3m)



5- After Rehabilitation (thickness 0.5m)



6- After Rehabilitation (thickness 0.5m with triangle width 2m)



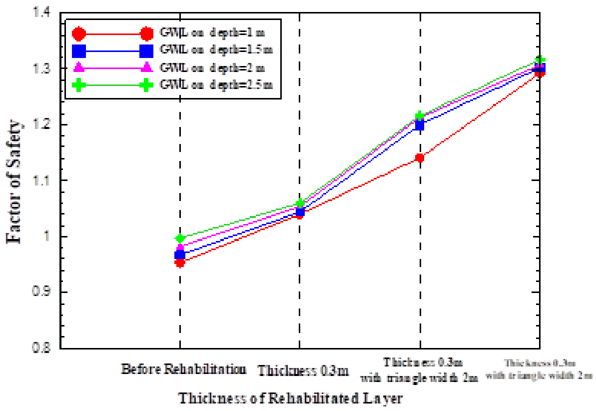
7- After Rehabilitation (thickness 0.5m with triangle width 3m)

Figure 15- factor of safety of Critical slip surface of canal before and after rehabilitation.

The acceptable limit of factor of safety should not be less than 1.5 the minimum acceptable limit of factor of safety is 1.5[26].Figure (15) shows that the canal before rehabilitation was almost unstable, with a factor of safety below the acceptable limit of 1.5. After rehabilitation, the factor of safety increased substantially. The triangle of cobbles (rehabilitated layer) was particularly effective in increasing the factor of safety of the canal slope at critical conditions, making it more stable.

5.3.3. The Effect of Position of Groundwater Table on Slope Stability

Based on the data, Depth to GWT is 1m from land surface (bank level) In this study, four different groundwater table positions and typical are simulated in the numerical analyses to determine the slope safety factors of the canal before and after rehabilitation. Figure (16) shows the effect of groundwater table position on slope stability.



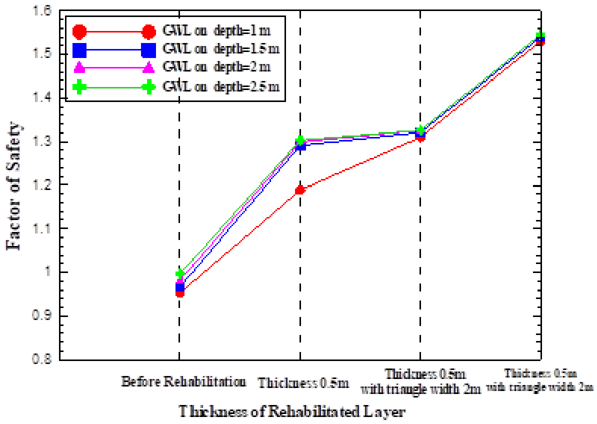


Figure 16- The effect of lowering water table level on the factor of safety.

As the groundwater table rises, the factor of safety of soil decreases[32]. Figure (17) shows the relationship between the factor of safety (FS) and the depth of the groundwater for a canal. The linear fitting line is shown in equation (4), which has a correlation coefficient of 0.9901.

$$FS = 0.0307 * Depth + 0.9215 \quad \text{(Equation 4)}$$

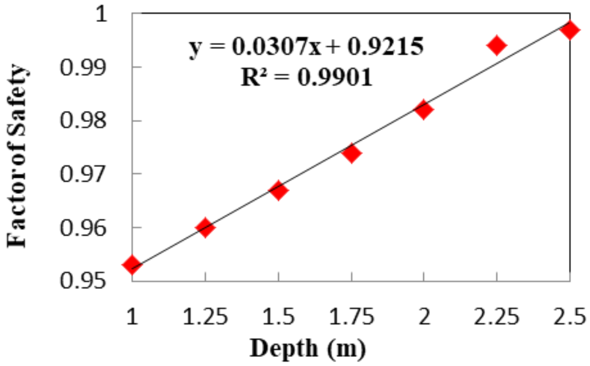


Figure 17- The variation of factor of safety with respect to groundwater depth.

5.3.4. Coupled and Uncoupled Approaches for the Prediction of Heave in Soil Subjected to Irrigation Canal

The main interactive processes in the volume change analysis of unsaturated expansive soils are stress deformation and water flow[33]. The commercial finite element based programs SIGMA/W and SEEP/W are developed to solve soil problems using fully coupled (SIGMA/W) or one of several uncoupled options(SEEP/W)[34]. Hydro-mechanical coupling effects on the factor of safety (FS) are investigated in this study. Uncoupled analysis refers to conducting volume change-induced stress analysis after completing seepage analysis. This approach does not consider the effect of expansive soil volume changes on flow behavior[35]. Figure (18) shows the variation of FS of canal before and after rehabilitation based on coupled and uncoupled analysis.

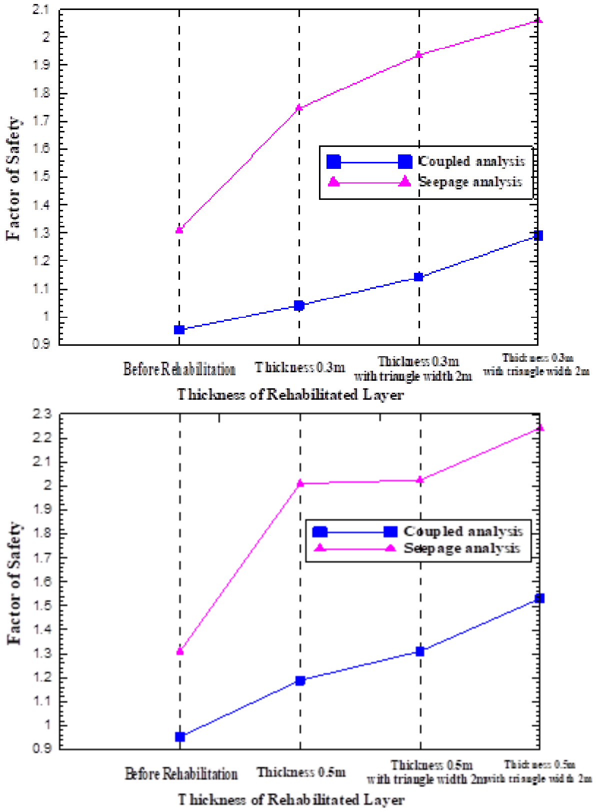


Figure 18- FS Comparison of coupled and uncoupled analysis for canal before and after rehabilitation

Figure (18) show that the variation between uncoupled and coupled analysis. The uncoupled analysis is higher FS values than the coupled analysis.

6. Conclusion

In this research study, results of numerical analysis of lower Al-kharit irrigation canal in Upper Egypt rested on expansive soil is studied. The main conclusions from this study are as follows:-

1. After validation GeoStudio with Plaxis 2D, the simulation models by GeoStudio can be used as a reliable tool to predict heave of expansive soils under different proposed working cases.
2. Increased saturated permeability will shorten the time for expansive soil to reach steady state.
3. The thickness of expansive soil increases , the more the expansive soil heaves
4. As increasing the thickness of expansive soil, increases its swelling potential.

5. Rehabilitation canal on expansive soil is an effective and useful way to reduce the effects of suction that cause soil sweeling.
6. The minimum factor of safety (0.953) was obtained, when the analysis considered before rehabilitation. After rehabilitation canal, the factor of safety of the soil increased to 1.53 (at case of thickness rehabilitation 0.5m with triangle width 3m), indicating a successful design of the slope (safe case).
7. The uncoupled analysis can overestimate the slope stability of canal. This means use of uncoupled analysis in engineering practice may lead to unsafe design.

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