Factors Affecting on Stability of Waterways Embankments

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***Abstract*— Stability of waterways embankments is one of the most important problems in water engineering works because the failures could cause catastrophic environmental and human disaster, in addition to large economic losses due to such failures. The purpose of this research is to investigate and study the factors affecting on stability of waterway embankments and stabilization method, the factors affected on stability of embankments in this research included into the fluctuation of water level in both canal (H_c) and inside embankments (H_e) also the drawdown cases, the inclination of waterways embankment and type of soil. The analysis of the embankment is performed by the finite element program (Phase^2) and the safety factor is calculated using the shear strength reduction method (SSRM). A Consistent increase in the safety factors (F.O.S) is noticed as a result of increasing the soil shear strength parameters. The drawdown cases have a noticeable effect on the stability of embankments for a non-cohesion soil (sand), especially a case of rapid draw down, In general the friction soil is a more sensitive for the fluctuation of water level in both canal (H_c) and inside embankments (H_e) than cohesive soil. The factor of safety (F.O.S) increased significantly with increasing water level in canal (H_c) in case of cohesive soil more than a sandy soil, this is because of the great impact of the cohesion (C kpa), the flatter inclination of embankments have a noticeable effect on increasing the stability.**

Keywords*— *Slope Stability, Numerical Analysis, Seepage, Drawdown.

I. INTRODUCTION

Slope stability is considered one of the most strategic issues in civil engineering. Slopes could fail under different types of external loads(Salem, Mashhour et al. 2012), changing in the surrounding environmental conditions such as the fluctuation in water table in canal (H_c) and inside embankment of waterway (H_e) and many other reasons could cause such failures in the slope (Berilgen 2007). In general, there are three drawdown modes as shown in

Figure 1, as fully rapid drawdown, fully slow drawdown and transient drawdown, in analyzing the stability and failure mechanism for a waterways embankments subjected to the water level change (Huang and Jia 2009, Nian, Jiang et al. 2011). The simplest solution to handle with slope failures is avoiding the failed zones. For cohesive soils, the shear band (failure surface) is deep, On the other hand, for cohesionless soils, the shear band is shallow (Salem, Hassan et al. 2008), for this reasons many stabilizing systems are used in order to stabilize slopes and to increase the slope safety factors to avoid expected failure.

The stability of a slope depends on its geometry, soil properties, and fluctuation on water levels in both canal and inside embankment and the drawdown condition, the change in canal water level happens without allowing the time needed for the drainage of the slope soil, it is called a rapid drawdown. Due to rapid a drawdown there will be a decrease in the slope stability, which may lead to slope failures (Nian, Jiang et al. 2011).

A slope stability analysis was conducted on the model to assess the consistency of selected side inclination (1.5H to 1V) versus another flatter (2H to 1V) one. The analysis revealed that (2H: 1V) side slope would provide a more reliable factor of safety (F.O.S) leading to minimized risk of failure ensuring stability (Salem, Hassan et al. 2008).

Slope stability can be increased in different ways such as: flattening of slopes by modifying the ground surface geometry (Jebelli and Meguid 2013), carrying out surface and subsurface drainage, using soil improvement techniques, installing retaining structures such as walls or piles. The first remedy leads to a reduction of the driving forces for failure; the other measures in general produce an increase of the resisting forces. Piles have been used successfully in many situations in order to stabilize slopes or to improve slope stability (Ausilio, Conte et al. 2001).

Stabilizing piles are one of the widely used techniques in stabilizing slopes. Many researches and approaches were proposed to have a better understanding of the effect of the stabilizing piles on different slopes types. Stabilization method that has been used to improve the stability of slopes has been via the installation of micropiles on the embankment by drilling a borehole, placing reinforcement, and grouting the hole (Pinyol and Alonso 2011).

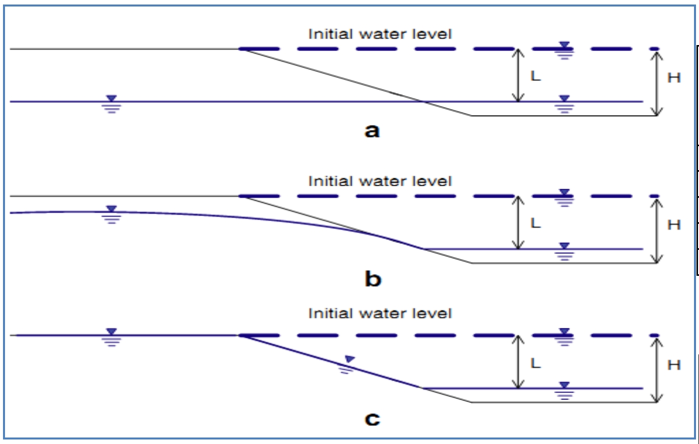

Figure 1. Slow drawdown b) Transient drawdown c) Rapid drawdown.

II. PARAMETRIC STUDY

In this study, an embankment of homogenous single soil layer is modeled for two type of soil to analyze the parameters effect on stability of embankment as shown in Table 1. The first type is a cohesionless soil ($\emptyset$ *soil*) and the second type is a cohesion soil with properties as shown in **Error! Reference source not found.**. Figure 2 illustrates a schematic diagram for the studied slope geometry and configuration.

Where:

H = Slope height,

H_c = Height of water in canal,

H_e = Height of water inside embankment,

L/ H_c = drawdown ratio,

Z: 1 = Slope inclination, (2H: 1V) and (1.5H: 1V).

The soil properties are chosen to be in the practical range that simulates an actual geotechnical analysis, and these properties are:

C = Soil cohesion ranging between 30.0 and 50.0 (kpa) to cover soil consistencies medium stiff clay

$\emptyset$ = Soil angle of internal friction ranges between 30.0 to 40o to cover the soil relative densities from loose to dense soil.

The following parameters are chosen according to the chosen soil type (consistency and relative density).

The resulting performed program runs to cover almost all the above mentioned combinations of soil parameters.

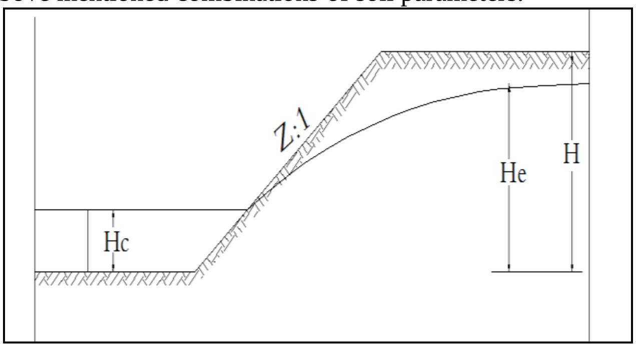

Figure 2. Canal cross section geometry

Table 1. Parameters used in the Parametric Study.

Case	Type of soil	Relative head in canal (H_c/H)	Relative head in embankment (H_e/H)	Side slope (Z:1)
1	Sand	0.0	0.0	2:1
2		0.2	0.2	
3	Clay	0.4	0.4	3:2
4		0.6	0.6	
5		0.8	0.8	

Table 2. Soil properties

Sand			
classification	Friction angle ($\emptyset$)	Es(MN/m2)	γ (KN/m3)
V-loose sand	27-30	3.0-30.0	14.0-16.0
Loose sand	30-32	10.0-25.0	15.0-17.0
Medium dense	32-36	25.0-75.0	16.0-18.0
Dense	35-40	75.0-150.0	17.0-19.0
Very dense	>40	150.0-400.0	18.0-20.0
Clay			
classification	C_u(KN/m^2)	E_s(MN/m^2)	γ (KN/m^3)
Very soft	0.0-12.5	-	-
Soft	12.5-25.0	0.5-2.0	14.0-16.0
Medium stiff	25.0-50.0	1.5-6.0	15.0-17.0
Stiff	50.0-100.0	2.5-10.0	16.0-18.0
Very stiff	100.0-200.0	5.0-20.0	17.0-19.0
Hard	>200	10.0-40.0	18.0-20.0

III. NUMERICAL MODELING OF THE EMBANKMENT

The finite element software Phase^2 is used in modeling the embankment of waterway. The software is a 2-dimensional elasto-plastic finite element program; it can be used to solve slope stability and problems at the field of civil engineering. The factor of safety (F.O.S) is calculated using the Shear Strength Reduction method (SSRM),(PHASE^2 Version 8.005, 2011). The failure criterion used in the slope analysis is Mohr-Coulomb criterion. In Phase^2 program, the pile is modeled using structural elements with pile/soil interface, and the properties of the interface didn't significantly affect the model results because of the rigidity of pile material and soft nature of the surrounding soil. Piezometric lines are used to model the water level in the program in case of rapid drawdown as shown in Figure 3, and the finite elements are used to model the water level in the other two cases of drawdown (transient and slow drawdown).

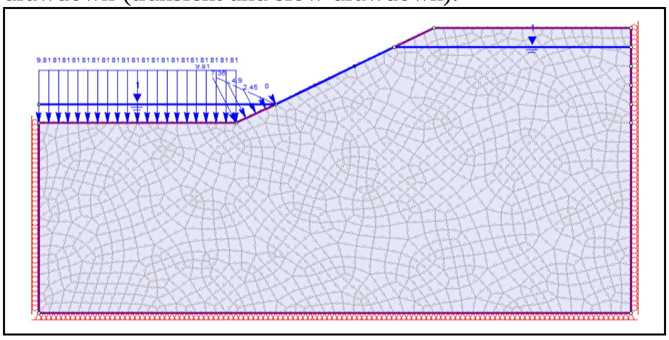

Figure 3. Modeling of the Water Table Using Piezometric Line

IV. ANALYSIS AND RESULTS

The previously mentioned parameters are input into the finite element program Phase^2, analysis of the parametric study results is presented hereinafter showing the effect of each parameter.

A. *Effect of Shear Strength Parameters*

As a soil mechanics fact, that increasing the soil shear strength parameters (c, ϕ) has a great influence in increasing the factor of safety (F.O.S) of slopes, because of increasing these parameters results in an increase in the soil shear strength, consequently, increasing the resistance force.

Effect of soil cohesion (c)

Keeping all other parameters constant and increasing the soil cohesion (C) only resulted in an increase in the safety factor (F.O.S) of slopes, Figure 4 indicates this fact. The relation between (F.O.S) and the soil cohesion (C) is approximately linear and the soil cohesion is directly proportional to the slope safety factor.

It is notice from the figure that for the lowest water level in canal (H_c=0.0) a safety factor (F.O.S) increase with increasing a strength parameter for a cohesion soil (C kpa), for increasing a value of cohesion from (C=30kpa) to (C=50kpa) the safety factor (F.O.S) increased from 1.97 to 3.29 by increasing a ratio 67%, for the same value of cohesion with increasing water level in canal (H_c) a safety factor increase with a variable ratio from 13.0% for two water levels (H_c=0.0) and (H_c=0.2H) to 25.0% for two canal water levels (H_c=0.6H) and (H_c=0.8H).

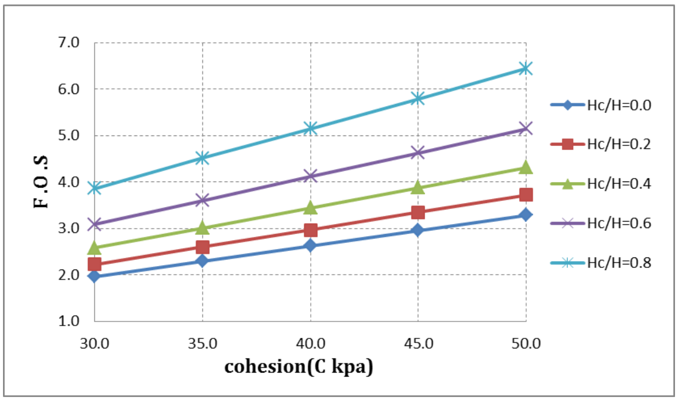

Figure 4 Effect of cohesion (C kpa) on safety factor (F.O.S) (H=5.0m, side slope 2:1, clay, without stabilizing pile)

Effect of soil angle of internal friction (Ø)

Figure 5 shows the relation between the internal angle of friction (Ø) and the safety factor of the slope (F.O.S) for different height of water in canal (H_c) with respect to total height of slope (H). It is obvious from the figure that increasing the internal angle of friction (Ø), resulted in a clear increase in the safety factor of slope (F.O.S), the relation between the safety factor and the soil angle of internal friction (Ø) is approximately linear. It is notice from the figure that for the lowest water level in canal (H_c=0.0) a safety factor (F.O.S) increase with increasing a strength parameter for a cohesion less soil (Ø soil). In case of maximum water level in canal (H_C=0.8H) increasing a value of friction angle from (Ø=30°) to (Ø=40°) the safety factor (F.O.S) increased from 1.15 to 1.68 by increasing ratio reached 46.0%. for the same value of friction angle (Ø) with increasing water level in canal (H_c) a safety factor increase with a variable ratio from 5.7% for two water levels (H_c=0.2H) and (H_c=0.4H) to 19.1% for two canal water levels (H_c=0.6H) and (H_c=0.8H).

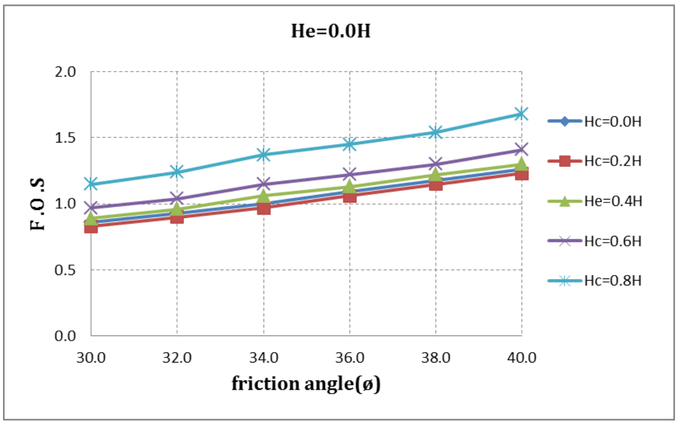

Figure 5. Effect of friction angle (ø) on F.O.S (H=5.0m, He=0.0, side slope 3:2, sand, without stabilizing piles)

B. *Effect of Water Level in the canal (H_C)*

The presence of water level in canal (H_C) beside slopes forms an additional stabilizing water pressure triangle which results in additional safety into the slope. The water pressure along the embankment side is equal to ($\gamma_w \times H_c$) where (γ_w) is the water density and (H_c) is the selected water depth. Figure 6 shows the effect of the water level in the waterway beside the embankment of clay soil. The slope safety factor increased with increasing the water depth in the canal. It is obvious from the figure that increasing the cohesion (C kpa), resulted in an increase in the safety factor for slope, for the same water level in embankment (He), safety factor (F.O.S) also increased by a variable ratio with increasing water level inside canal (HC), for the same water level inside embankment (He=0.0) and cohesion (C=30 kpa) the safety factor increased from 1.97 at zero water level in canal (Hc=0.0) to reach 2.23 at (Hc=0.2H) with increasing ratio about 13.2%, the safety factor (F.O.S) increased to reach 2.58 at (Hc=0.4H) and 3.09 at canal water level (Hc=0.6H) by increasing ratio 19.76%, the maximum increasing occurred at the highest canal water level (Hc=0.8H) was 3.86 with increasing ratio 24.9%. It is obvious from the figure that a safety factor increased with a constant ratio with increasing the cohesion of soil (C kpa) as it is noticed before from Figure 4.

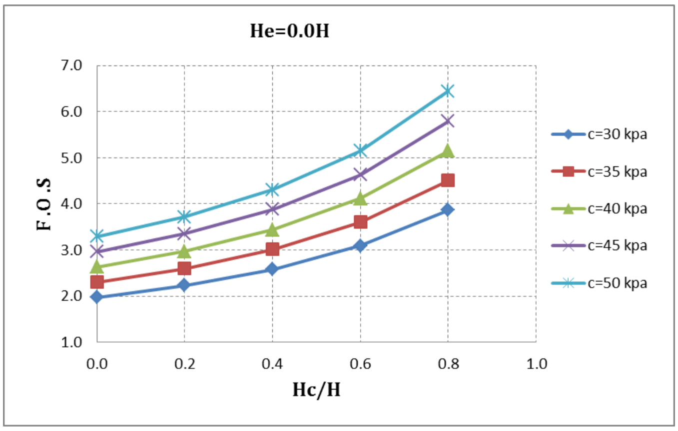

Figure 6. Effect of canal water level on F.O.S (H=5.0m, H_e=0.0, side slope 3:2, clay, without stabilizing piles)

Figure 7 shows the effect of the water level in the waterway beside the embankment of sand soil. It is obvious from the figure that increasing the internal angle of friction ($\emptyset$), resulted in a noticeable increase in the safety factor for slope, for the same water level in embankment (He). For zero water depth in canal (H_c=0.0) the safety factor is a little more than the case of (H_c=0.2H), this happened because of the water which saturate a toe of slope and this water make a lubrication for soil particles and decreasing the internal friction between particles, by increasing water level in canal a safety factor return to increase again, the rate of increase of safety factors for highest canal water level is a higher than occurred in a low water levels. It is obvious from the figure that for internal angle of friction ($\emptyset = 40°$) the safety factor (F.O.S) is 1.26 in case of zero water level in canal (H_C=0.0) and decreased slightly to reach 1.23 at canal water level (H_C=0.2H) by decreasing ratio 2.4%, a safety factor (F.O.S) return to increase again with a variable ratio to reach 1.3 at water level in canal (H_C=0.4H) by increasing ratio around 5.7%, with increasing a canal water level the safety factor increased to reach 1.41 by increasing ratio 8.5% at water level (H_C=0.6H), the maximum increasing occurred at the highest water level (H_C=0.8H) as safety factor is 1.68 with an increasing ratio reach 19.1%.

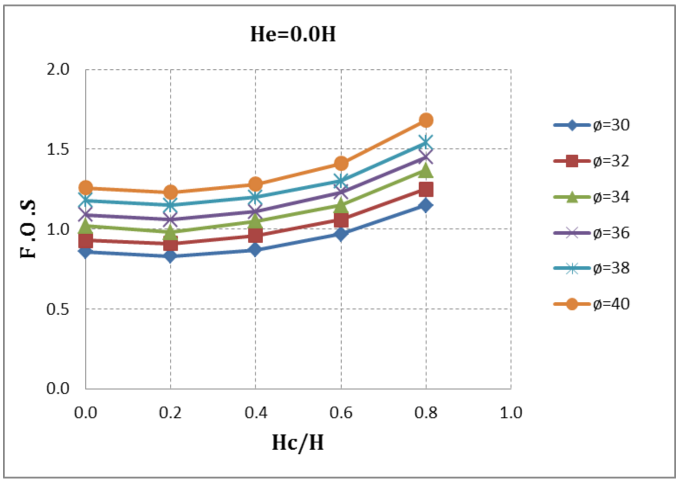

Figure 7. Effect of canal water level (H_C) on F.O.S (H=5.0m, H_e=0.0, side slope 3:2, sand)

Figure 8 show the clear difference between the safety factor on both two soil sand and clay , It is obvious from the figure that in case of clay soil the safety factor (F.O.S) is more great than a safety factor for a sand soil which have the same value in cohesion (C 30 kpa) and internal friction angle ($\emptyset = 30°$), also the effect of increasing a cohesion is more greater than the effect of increasing internal friction angle, the safety factor at canal water level (H_C=0.8H) is 1.15 for sand soil and 3.84 for clay soil and the behavior of clay is not like the behavior of sand at the low canal water levels, where in case of clay (cohesion) soil the safety factor behavior increased by raising water level in canal from (Hc=0.0 to Hc=0.8H).

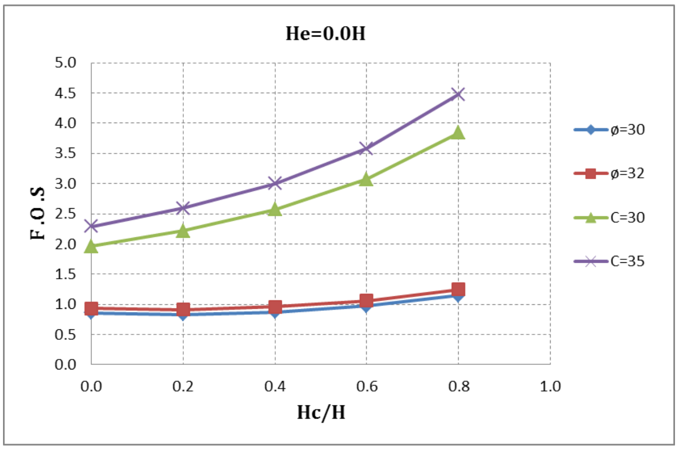

Figure 8. Effect of canal water level on F.O.S (H=5.0m, H_e=0.0, side slope 3:2,)

C. *Effect of Water Level inside embankment (H_e)*

The presence of water level inside embankment (H_e) make the embankments to be saturated and it`s weight to be a higher which is associated with higher failure driving forces, Specially In a rapid drawdown case will be the most critical case for sand soil, as a sudden removal of the water level in canal, and consequently the water pressure triangle, while the embankment slope is still being fully saturated and thus having the highest possible unit weight. Figure 9 shows the effect of the water level inside the embankment for sand soil in case of transient drawdown, the slope safety factor (F.O.S) decrease with increasing the water depth inside the embankment (H_e). The most critical case is considered when the canal is empty and the soil is saturated, as noted above. It is obvious from the figure that increasing the internal angle of friction ($\emptyset$), resulted in a noticeable increase in the safety factor for slope, for the same water level in canal (H_c).

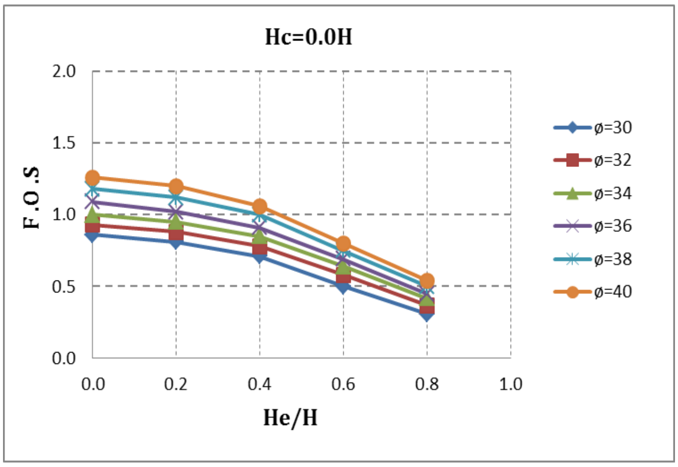

Figure 9. Effect of water level inside embankment on F.O.S (H=5.0m, H_C=0.0, side slope 3:2, sand, transient drawdown)

D. Effect of drawdown rati(L/H_e).

Drawdown ratio is defined as a ratio between the depression occurred in a canal water level (L), (L=[H_e-H_C]) and the total water depth inside embankment (H_e) as shown in Figure 10, there is another expression which take a time into consideration, a drawdown rate is defined as a ratio between the depression occurred in a canal water level and the time it takes to reach the new water level in canal.

Figure 11, show the relation between a drawdown ratio [(H_e-H_C)/ H_e] and a safety factor (F.O.S) for transient drawdown case, It is obvious from a figure that the relation between safety factor and a drawdown (L/H_e) ratio is inversely relation, safety factor decreased with increasing drawdown ration from 0.0 to 60.0% after this domain the relation changed to become a proportional, the reason for this behavior noticed in analysis the effect of water level in canal, as when a canal water level decreased (H_C) the safety factor decreased also, and the effect of decreasing canal water level is the same effect of increasing drawdown ratio.

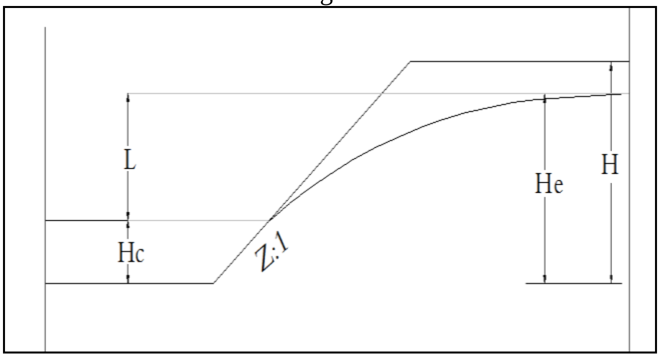

Figure 10. Drawdown ratio in case of transient drawdown [L/H_e]

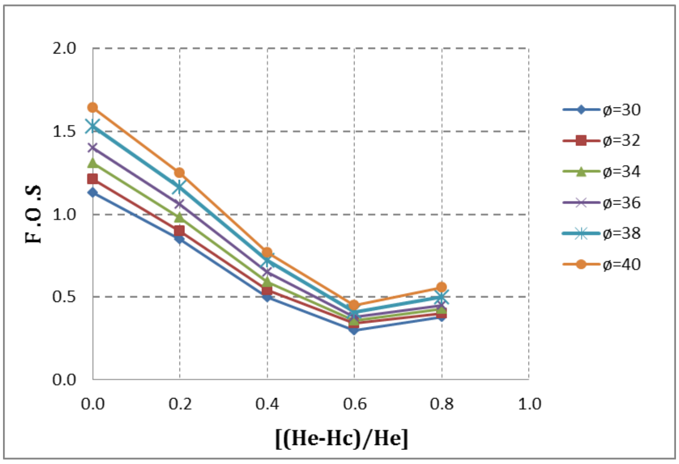

Figure 11 Drawdown ratio for a transient drawdown, (H =5.0m, H_e=0.8H, side slope 2:1, sand).

Figure 12, compare between the two cases of drawdown (rapid drawdown case and transient drawdown case), it is obvious from the figure that the case of rapid drawdown is the worst case and there is a large difference in the value of safety factor (F.O.S), as when the drawdown ratio (L/H_e=0.2) a safety factor (F.O.S) decreased from 0.85 in case of transient drawdown to 0.41 in case of rapid drawdown by decreasing ratio about 51.7%

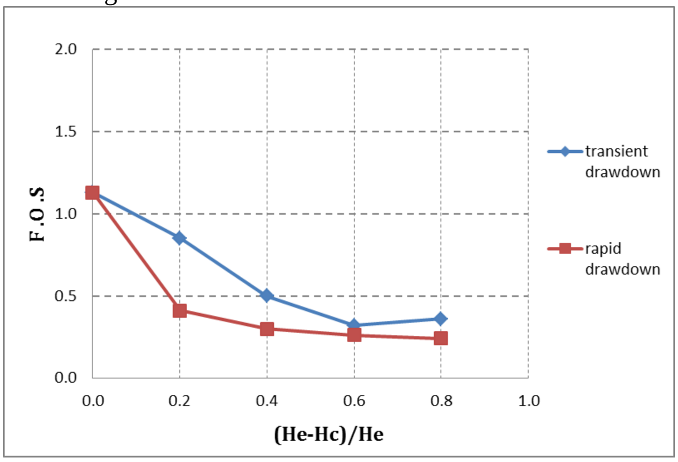

Figure 12. Comparison between a transient and rapid drawdown cases (H=5.0m, H_e=0.8H, side slope 2:1, sand)

E. Effect of slope inclination

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Figure 13, shows the relation between water levels inside embankments (H_e), and the (F.O.S) for two slope inclination (2H: 1V) and (3H: 2V). The relation between the slope inclination and (F.O.S) is an inversely proportional relation, such that increasing the slope inclination results in a decrease in the (F.O.S).

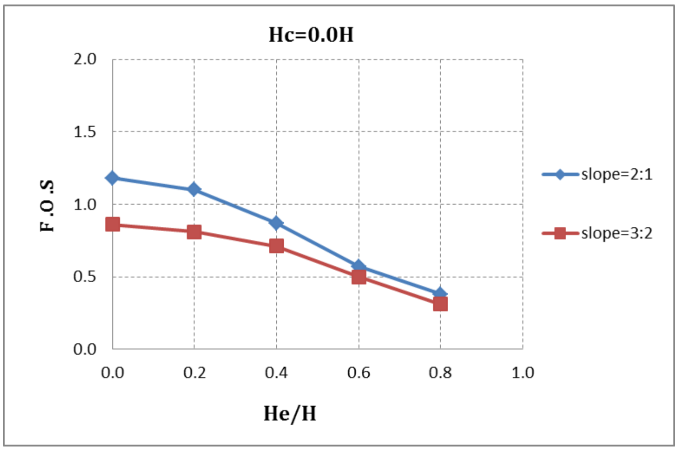

Figure 13. Effect of water levels inside embankment (H_e) on safety factor (F.O.S) at two side slope (2H: 1V) and (3H: 2V), (H = 5m, H_e=0.0, ø =30, sand, transient drawdown, without a stabilizing piles).

V. CONLUSION

Based on the analysis made by the finite element program (Phase^2), the following conclusions could be obtained:

[1] Soil Shear strength parameters (c, ø) are directly proportional to the safety factor.

[2] The relation between the water level in the waterway (HC) and the safety factor is a nonlinear proportional relation. The presence of water in the canal (HC) provides lateral resistance and additional weight against the sliding mass. The critical value of the safety factor is encountered when the slope is saturated and the waterway is empty (rapid drawdown case)

[3] The presence of water level inside embankment (He) make the embankments to be saturated and it`s weight to be a higher which is associated with higher failure driving forces.

[4] The drawdown case is one of the most important factors that control the safety factor (F.O.S), the relation between safety factor and a drawdown ratio (L/He) is inversely relation

[5] Smaller slope angles resulted in higher slope safety factors than steep slope.

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