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SLOPE STABILITY ANALYSIS OF AN EARTH DAM

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ABSTRACT: - The study of slope stability is important in the design and construction of the earth dams under influence of earthquake and some surcharge loads. Some factors affect the slope stability for the earth dam such as change the water level in the reservoir or rapid drawdown of the water level. In the present study, limit equilibrium methods and finite element method have been used to calculate the factor of safety of earth dam. The main objective is studying the influence the soil strength parameters including cohesion, angle of internal friction and unit weight of soil on the values of factor of safety of the upstream slope for earth dam. The results show that the values of factor of safety increase when the values of soil strength parameters (cohesion, angle of internal friction)and water level increased, and the value of unit weight of the soil decrease, and the values of factor of safety, decreasing fast in rapid draw down of the water level. The main conclusion is the stability of the earth dam increases when the soil strength parameters (cohesion, angle of internal friction) increase and unit weight of the soil decrease with increasing the water level in the reservoir and the earth dam may be exposed to the collapse in the case of the rapid drawdown of water level.

KEYWORDS: Earth dam, Slope stability, Simulation and analysis.

1- INTRODUCTION

Slope stability is important in the design and construction of earth dam because exposed to dangerous conditions for the end of construction that mean no water level in reservoir (dry condition for upstream side slope)and rapid drawdown condition when the removal upstream water pressure that supported the slope for earth dam, it causes a danger to the upstream slope .

There are many methods for slope stability analysis to assessment factor of safety such as (limit equilibrium and Finite element) methods by computer software, the limit equilibrium including different methods (Ordinary, Bishop, Janbu ,Morgenstern-price and Spencer) these methods applying the computer program SLOPE/W is applied to define the potential slip surface and calculate the factor of safety of homogenous earth dam under change water level condition and rapid draw down for the reservoir with time. The minimum required of factor of safety for earth dams equal (1.3) for upstream slope (1).

Calculated the values of factor of safety of downstream and upstream slope for (NIAN) dam in IRAN for end construction. And the values of factor of safety of upstream slope for sudden drop in water level (rapid drawdown). And steady state seepage for downstream slope. by used (Ordinary, Bishop, Janbu, Spencer) methods, by using (Geo-studio)software (SLOPE/W and SEEP/W)programs.

The study showed, the value of factor of safety for the upstream slope in the end of construction greater than the value of factor of safety in the sudden drop in water level(rapid drawdown)and the value of factor of safety for the downstream slope in the end of construction greater than the value of factor of safety in the steady state seepage, while the earth dam still stable(2). Calculated the values of factor of safety for the dams in (Queensland-

Australia), for drawdown rates of the reservoir with time by using slope/w and seep/w programs. The study showed the values of factor of safety for upstream slope increase for a low rate of reservoir drawdown (3).

Recently, many researchers in Iraq, such as (4, 5), interested in their research into the subject of the influence of several parameters on the factor safety for slope stability. In this study, the minimum values of the factor of safety are calculated using Limit equilibrium methods and Finite element method, when change values of (cohesion, angle of internal friction and unit weight of soil) and change water level in the reservoir, and rapid draw down of the water level.

2- METHODOLOGY OF STUDY

2-1 Materials properties of the earth dam

In this study take the values of the soil strength parameters of the earth dam as shown in table (1). The earth dam (homogenous) which its dimensions are: the width of the crest for the dam(B)=constant=10 m,(b) =constant=4m as shown in Figure(1), the water level are taken as a ratio from the height of earth dam (H=10m) of (h=0, 0.2H, 0.4H, 0.6H, 0.8H).

2-2 Slope stability analyses methods

Limit equilibrium methods are important in slopes stability analyses. These methods calculate the factor of safety (F) by dividing a potential sliding mass into several vertical slices. There are several methods to evaluate the static stability of earth AL-Wand dam these methods including:

The Ordinary or Fellenouis method: Fellenouis (1936) was developed this method and is sometimes referred to as “Fellenouis method.” The Ordinary method are satisfies the moment equilibrium for a circular slip surface, but neglects both the inter slice normal and shear forces. The advantage of this method is its simplicity in solving the (F), since the equation does not require an iteration process. The (F) is based on moment equilibrium and computed as: Abramson et al. and Nash as cited in (6).

$$F = \frac{\sum(c' \, l + (W \, \mathrm{Cos}\alpha - ul) tan\phi')}{\sum W sin\alpha} \quad \ldots\ldots\ldots\ldots \ (1)$$

Where c' and ϕ' = cohesion and internal friction angle respectively in effective stress terms.
l = the length of the slice base (m).
W=weight of each slice (kN).
u = pore water pressure (kN/m^2).
α = inclination of slip surface at the middle of slice.

Bishop Simplified Method: (Bishop, 1955), advanced this method is very common in practice for circular shear surface (SS), this method considers the inter slice normal forces but neglects the inter slice shear forces, this method satisfies moment equilibrium for (F) (1).

$$F = \frac{\sum \frac{c\,b + W\,tan\phi}{m_\alpha}}{\sum W \, sin\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The trial value is assumed for the factor of safety and the quantity, mα, is computed from the equation shown below

$$m_\alpha = \cos\alpha + \frac{\sin\alpha \; tan\phi'}{F} \quad \ldots\ldots\ldots\ldots(3)$$

Janbu’s simplified method: This method is based on a composite shear surface (i.e. non-circular) and the (F_f) is determined by horizontal force equilibrium. As in (Bishop Simplified Method), and this method does not satisfy moment equilibrium and considers inter slice normal forces (E) but neglects the shear forces (T). Janbu, 1954 as cited in (6), (F_f) is computed by:

$$F_f = \frac{\sum(c'l + (N - ul) tan\phi') sec\alpha}{\sum W \, tan\alpha + \sum \Delta E} \ldots\ldots\ldots(4)$$

ΣΔE = E2 − E1 = net inter slice normal forces (zero if there is no horizontal force).

Morgenstern-Price method: This method satisfies both force and moment equilibriums and assumes the inter slice force function. According to method Morgenstern-Price as cited in (7), the inter slice force inclination can vary with an arbitrary function (f(x)) as:

$T = f(x).\ \lambda\ .E$ ……….(5)

Where: f(x) = inter slice force function that varies continuously along the slip surface.

λ = scale factor of the assumed function.

E= inter slice normal force (kN).

Spencer's method: This method is the same (Morgenstern-Price) method except the assumption made for inter slice forces. A constant inclination is assumed for inter slice forces and the (F) is computed for both moment and force-equilibriums .According to this method, the inter slice shear force (T) is related to Spencer as cited in (6).

$T = E \tan \theta$ …………..(6)

E= inter slice normal force (kN).

θ=angle of inclination of inter slice resultant force.

Conventional methods: The finite element (FE) method available in software SEEP/W was employed to simulate 2-D steady-state and transient seepage in the earth dam before and during the drawdown, respectively.in this study use option (unsaturated-saturated seepage analyses).

SLOPE/W is a software product that uses theories and principles of the limit equilibrium methods to compute the factor of safety of earth slopes, that developed by GEO-SLOPE (Geo-Studio). International Canada is used for slope stability analysis. The comprehensive formulation of SLOPE/W makes it possible to easily analyze both simple and complex slope stability problems using a variety of methods to calculate the factor of safety.

SIGMA/W is a finite element software product that can be used to perform stress of earth structures. Its comprehensive formulation makes it possible to analyze both simple and highly complex problems. When coupled with SEEP/W, (another GEO-SLOPE software product), it can also model the pore-water pressure generation, this software use the equations of finite element method.

In this study (SLOPE/W 2007)has been applied separately and together with SEEP/W, SIGMA/W, based on finite elements mesh were coupled with slope stability analysis to determine the factor of safety, this is the key issue on slope monitoring gradually drawdown for the water level and long-term stability study (8).

3- RESULTS AND DISCUSSION

In this study, the factor of safety calculate to the upstream slope of earth dam by (Morgenstern-price (M1), Spencer(M2), Bishop(M3), Janbu (M4), Ordinary(M5)) and finite element method(FEM). The minimum value factor of safety (F) (critical slip surface) for the upstream slope with various parameters such as the soil strength parameters (cohesion, angle of internal friction and unite weight of soil) are study and the values of (F) calculate by (M1) because this method satisfies all the static equilibrium conditions which consist of moment and force equations and thus will produce a more validation for the factor of safety.

In the cases (1) the model built to end of construction (dry condition), there is no water table present in the reservoir and in the embankment dam body. After that take many cases with change the gradually rise of the water level (h) for the reservoir and then the gradually drawdown of the water level (h) for the reservoir with time. Another case used rapid drawdown for the water level in reservoir of the earth dam.

Also, in this study the shape of the critical slip surface of the upstream slope for the earth dam is analyzed using circular failure surface as shown in Figure (2).

The effect of different values of strength soil (c) with various values for angle of internal friction have study on the factor of safety when the (dry condition) that means no water table present in the reservoir and in the embankment dam body. The factor of safety increase with increases both values of (c) and (phi) at 16 and 21 kN/m^3 soil density as shown in Figure (3) and Figure (4).

Where result shown that the values of factor of safety increase between (1.548 to 2.403) because increasing the cohesion force of soil, leads to increasing the resisting forces for slip surface and make the slope stability more fix and give increased the value of factor of safety.

Also we draw the relationship between the factor of safety and cohesion at γ=21kN/m^3, the values of (factor of safety =1.347-2.131) when the values of (cohesion= 20-35 kN/m^2), for different values (phi) at (gamma=21 kN/m^3), because increasing the cohesion of soil, leads to increasing the resisting forces for slip surface (shear strength) that increased the value of factor of safety.

To know the effect of the unit weight (γ) of the dam soil on the factor of safety as shown in Figure (5), the relationship between the factor of safety and cohesion when the value of(phi=22^o). Also noted when the value of unit weight (gamma=16-21 kN/m^3) the values of the (factor of safety=1.347-2.162), because increased the weight of the sliding mass and decrease the resisting force.

Table (2) shows increasing the value of factor of safety with the increasing water level (h) and the values of (cohesion, angle of internal friction)on diagonal lines well taken, when (γ=16 kN/m^3)

From the Figure (6), the values of (factor of safety=1.541-3.701) when the water level (h =2-8 m), for different values (cohesion and angle of internal friction) at (γ=16kN/m^3), because increasing the water forces that supported the upstream slope face this leads to increase the resisting forces. All results shown in Table (3) with same value of density and high of dam the value of factor of safety increasing with the increasing the water level (h) and the values of (cohesion, angle of internal friction) on diagonal lines well taken, when (γ=21 kN/m^3).

In Figure (7), the values of (factor of safety=1.333-2.742) when the water level (h =2-8 m), for different values (cohesion and angle of internal friction) at (γ=21KN/m^3), because increasing the water forces that supported the upstream slope face leads to increase the resisting forces

For gradually drawdown of the water level (h) for the reservoir with time, we considered the value of (F) for each earth dam less than (1.3) the dam will collapse, the researchers take specified numbers of the values of(c, ϕ) to calculate the values of factor of safety (F) in the cases of gradually drawdown of the water level (h) and rapid drawdown.

The calculation of the minimum values of factor of safety with gradually drawdown of the water level (h=8m) for the reservoir that means maximum storage , during (5 days) and calculation the minimum values of factor of safety during (25 days) when the reservoir is empty, that means (h=0), when (cohesion=20, 24, 28, 30, 33, 35 kN/m^2) and (angle of internal friction=22^o, 23^o, 25^o, 26^o, 28^o, 30^o) and (γ=16, 21 kN/m3) and divide the time within duration (0.5, 1.5, 2.5, 4, 6, 8, 11, 16, 22, 30) days.

From the Figure (8) the values of (factor of safety=3.308-1.391) when the (time=0.5-30)days, for different values (cohesion and angle of internal friction) at (γ=16kN/m^3), during the first(5 days) the values of factor of safety becomes decrease when the water level in the reservoir is drawdown quickly, because removal the water forces which supported the upstream slope face of dam, and in the same time the pore water pressure is still remained inside the dam body, which decreasing the resisting force. When the reservoir is empty during (25 days) the values of factor of safety become increasing with time it's started constancy, because pore water pressure dissipation gradually with time, which leads to increasing the values of factor of safety. and when the dam body become dry, the factor of safety started constancy.

From the Figure (9), the values of (factor of safety=2.559-1.235) when the (time=0.5-30)days, for different values (cohesion and angle of internal friction) at (γ=21kN/m^3), during the first(5 days) the values of factor of safety becomes decrease when the water level in the reservoir is drawdown quickly because removal the water forces which supported the upstream slope face of dam, and in the same time the pore water pressure is still remained inside the dam body, which decreasing the resisting force. When the reservoir is empty during (25 days) the values of factor of safety become increasing with time it's started constancy because pore water pressure dissipation gradually with time, which leads to increasing the values of factor of safety and when the dam body become dry, the factor of safety started constancy.

Figure(10) showed that the values of (factor of safety=0.997-1.787), when the (cohesion=20-35) kN/m^2 for (γ=16,21)kN/m^3, noted that the values of factor of safety increase because increasing the values of the cohesion of soil, leads to increasing the resisting forces for slip surface (shear strength) that increased the value of factor of safety.

For purpose comparison between the minimum values of factor of safety which calculate by different methods (Morgenstern-price (M1), Spencer (M2), Bishop (M3), Janbu (M4), Ordinary (M5)) and Finite element method (FEM), using SLOPE/W and SIGMA/W programs. We draw the relationship between the minimum values of factor of safety with gradually increase of the water level (h=8m), for (c=20kN/m^2, phi=22^o, γ=16kN/m^3).
Figure(11)the values of (factor of safety=1.492-2.318) which calculated by (M1, M2, M3, M4, M5, FEM) which simple differences between them and also for comparison between the minimum values of factor of safety which calculate by different methods (Morgenstern-price(M1), Spencer(M2), Bishop(M3), Janbu (M4), Ordinary(M5)) and Finite element method (FEM), by using SLOPE/W and SIGMA/W programs, we draw the relationship between the minimum values of factor of safety in case of gradually drawdown of the water level(h=8m) during (5 days) and calculate the minimum values of factor of safety during (25 days) when the reservoir is empty with time(days),for (c=20kN/m^2, phi=22^o, γ=16kN/m^3).

From Figure (12), it can be noted that the values of (factor of safety=2.144-1.317) which calculated by (M1, M2, M3, M4, M5, FEM) which simple differences between them.
And also for comparison between the minimum values of factor of safety which calculate by different methods (Morgenstern-price (M1), Spencer (M2), Bishop (M3), Janbu (M4), Ordinary (M5)) using SLOPE/W program draw the relationship between the minimum values of factor of safety with (cohesion =20-35kN/m^2,phi=22^o,γ=16kN/m^3),in case of rapid drawdown of water level(h=8m).
From Figure (13) the values of (factor of safety=1.065-1.903) which calculated by (M1, M2, M3, M4, M5) which simple differences between them about factor of safety.
The differences between all values of factor of safety which passed previously agree with what Duncan as cited in (9) which refers that "The differences between the values of the safety factor obtained with the various methods are generally lower than 6%" while the values of factor of safety calculated by (FEM) little higher pervious values.

4- CONCLUSIONS

From the results of this study the researchers placed the following conclusion:
The slope stability of the upstream slope for earth dam increasing when the soil strength parameters (cohesion, angle of internal friction) increase and storage of the water, the slope stability of the upstream slope for earth dam decreasing when the soil strength parameter (unite weight of soil) increase. The earth dam may be exposed to the collapse in the case of the rapid drawdown of water level.

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Table (1): Material properties of earth dam model [(10, 11)]

Permeability(m/sec)	Modulus of Elasticity(kN/m^2)	Poisson's ratio	Unit weight(kN/m^3)	Cohesion (kN/m^2)	Angle of internal friction(deg.)
10^{-9}	10000	0.334	16, 21	20	22
				24	23
				28	25
				30	26
				33	28
				35	30

Table (2): Minimum values of factor of safety for increase progressively (h) at (γ=16kN/m^3

γ	H(m)	h(m)	ϕ \ c	20	24	28	30	33	35
16	10	2	22	1.541	1.713	1.879	1.962	2.087	2.171
			23	1.574	1.749	1.915	1.999	2.123	2.207
			25	1.641	1.882	1.989	2.072	2.197	2.281
			26	1.676	1.854	2.027	2.11	2.235	2.318
			28	1.747	1.925	2.103	2.188	2.313	2.396
			30	1.82	1.998	2.177	2.266	2.394	2.477
16	10	4	22	1.632	1.82	2.008	2.102	2.24	2.33
			23	1.667	1.855	2.043	2.137	2.278	2.368
			25	1.738	1.927	2.115	2.208	2.349	2.443
			26	1.772	1.963	2.151	2.245	2.386	2.48
			28	1.84	2.039	2.227	2.321	2.461	2.555
			30	1.911	2.114	2.305	2.734	2.54	2.634
16	10	6	22	1.857	2.084	2.305	2.414	2.575	2.683
			23	1.894	2.121	2.346	2.454	2.616	2.723
			25	1.968	2.195	2.423	2.536	2.698	2.806
			26	2.007	2.234	2.461	2.574	2.74	2.848
			28	2.085	2.312	2.539	2.653	2.823	2.935

			30	2.164	2.394	2.621	2.399	2.905	3.018
16	10	8	22	2.264	2.556	2.835	2.975	3.185	3.325
			23	2.304	2.599	2.88	3.02	3.229	3.369
			25	2.386	2.681	2.971	3.22	3.32	3.49
			26	2.427	2.722	3.017	3.157	3.367	3.507
			28	2.513	2.808	3.103	3.251	3.462	3.602
			30	2.603	2.897	3.192	3.34	3.561	3.701

Table (3): Minimum values of factor of safety for increase progressively (h)at(γ=21kN/m^3)

γ	H(m)	h(m)	ϕ \ c	20	24	28	30	33	35
21	10	2	22	1.333	1.468	1.602	1.669	1.763	1.826
			23	1.367	1.501	1.635	1.702	1.8	1.863
			25	1.436	1.57	1.704	1.771	1.871	1.938
			26	1.471	1.605	1.739	1.806	1.907	1.974
			28	1.537	1.677	1.811	1.878	1.979	2.046
			30	1.604	1.753	1.886	1.953	2.053	2.121
21	10	4	22	1.385	1.533	1.675	1.743	1.846	1.914
			23	1.418	1.566	1.711	1.779	1.882	1.951
			25	1.485	1.633	1.781	1.853	1.959	2.025
			26	1.52	1.667	1.815	1.889	1.994	2.063
			28	1.59	1.738	1.815	1.959	2.07	2.141
			30	1.663	1.811	1.958	2.032	2.143	2.217
21	10	6	22	1.514	1.68	1.836	1.915	2.39	2.428
			23	1.548	1.717	1.874	1.952	2.07	2.111
			25	1.617	1.786	1.95	2.029	2.146	2.148
			26	1.652	1.822	1.99	2.068	2.186	2.225
			28	1.725	1.894	2.064	2.148	2.266	2.264
			30	1.8	1.97	2.139	2.224	2.349	2.344
21	10	8	22	1.705	1.896	2.082	2.175	2.315	2.408
			23	1.741	1.935	2.121	2.215	2.359	2.447
			25	1.813	2.014	2.202	2.295	2.435	2.528
			26	1.85	2.051	2.243	2.336	2.476	2.569
			28	1.926	2.127	2.328	2.421	2.561	2.654
			30	2.006	2.206	2.408	2.508	2.649	2.742

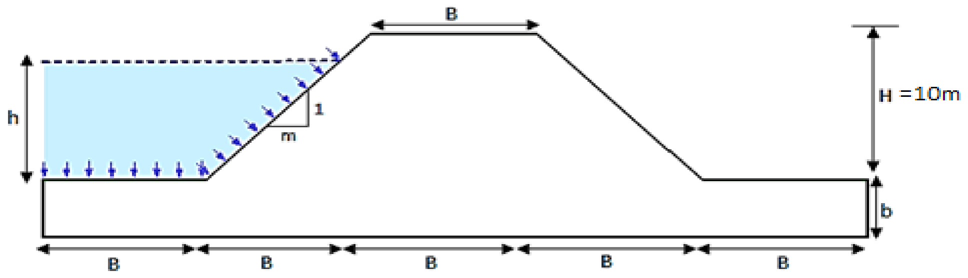
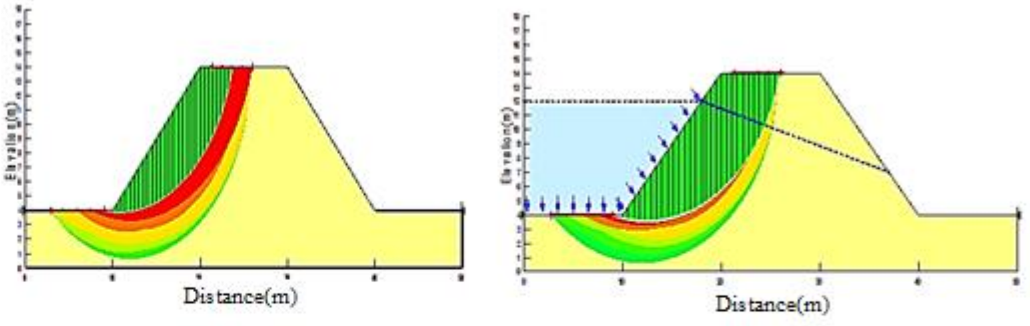


Figure (1): Earth dam geometry with dimensions.



(a) h=0 (b) h=8m

Figure (2): Critical slip surface for analysis of earth dam with and without water table.

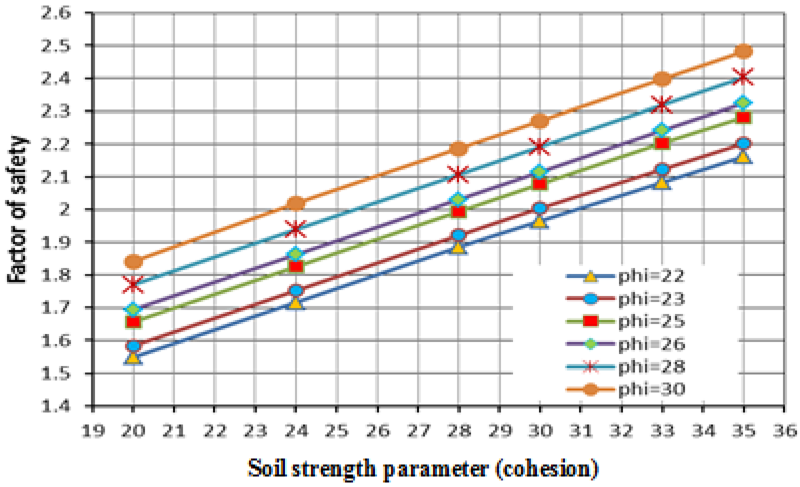


Figure (3): Factor of safety vs. soil strength parameter (cohesion) at γ=16kN/m^3.

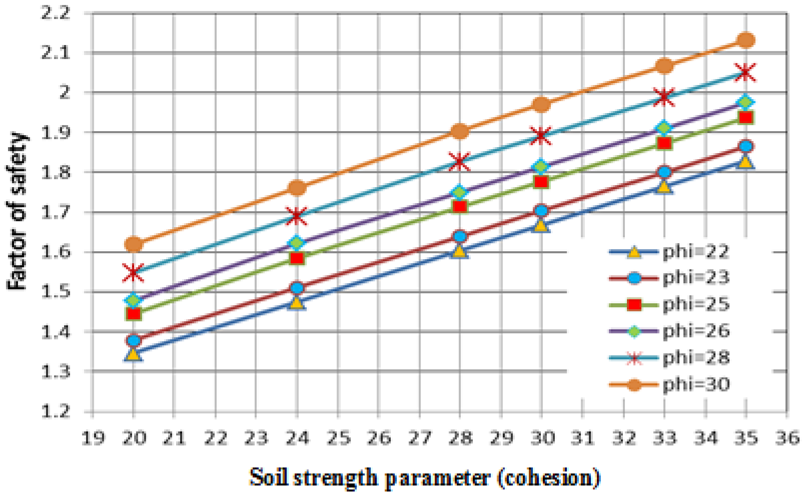


Figure (4): Factor of safety vs. soil strength parameter (cohesion) at γ=21kN/m^3.

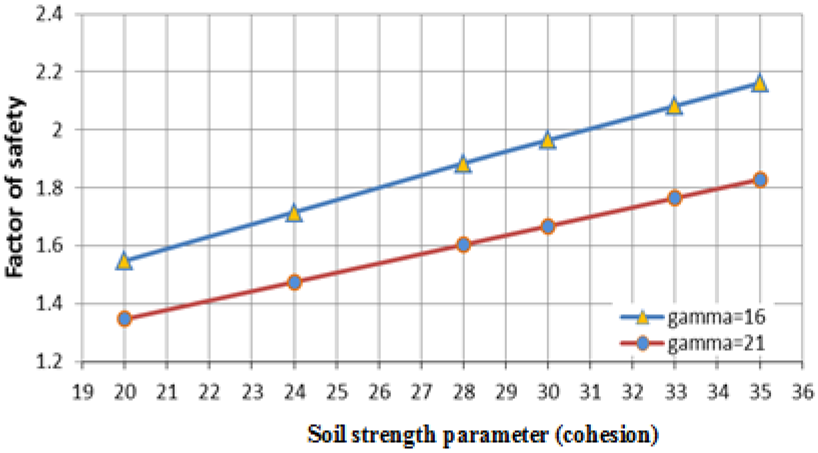


Figure (5): Factor of safety vs. soil strength parameter (cohesion)at(γ=16 and 21)kN/m^3

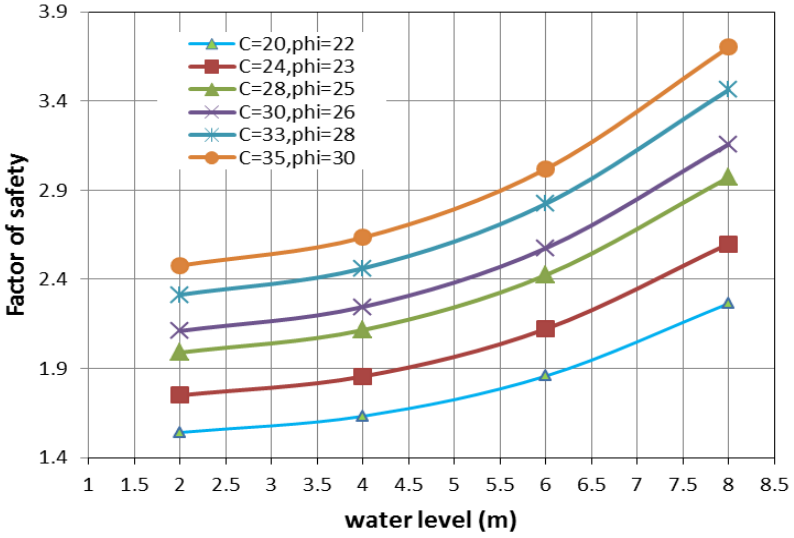


Figure (6): Factor of safety vs. water level (h) at (γ=16)kN/m^3.

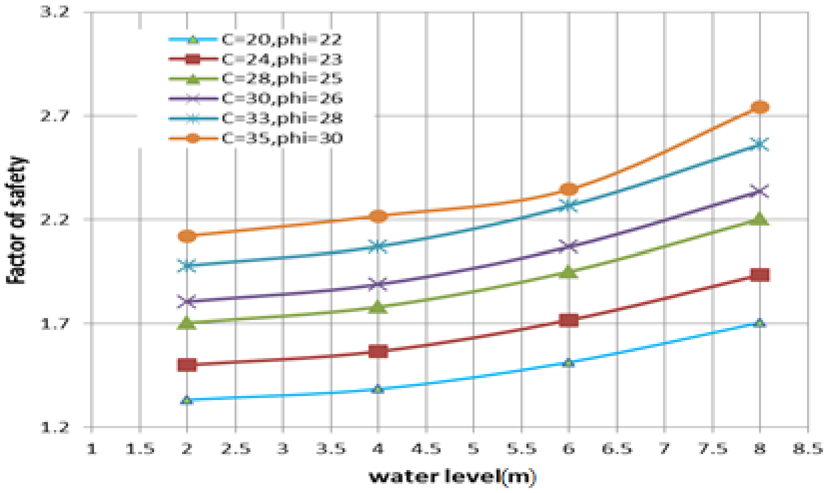


Figure (7): Factor of safety vs. water level (h) at (γ=21)kN/m^3.

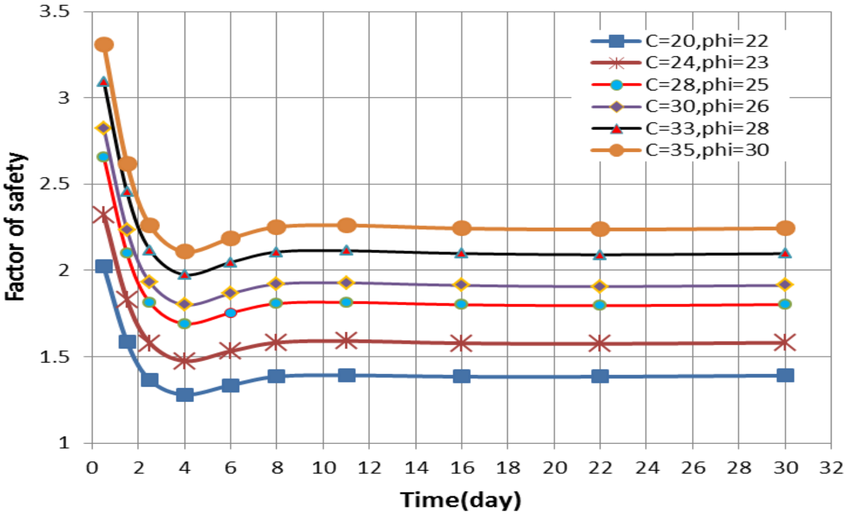


Figure (8): Factor of safety vs. time(day) at (γ=16)kN/m^3.

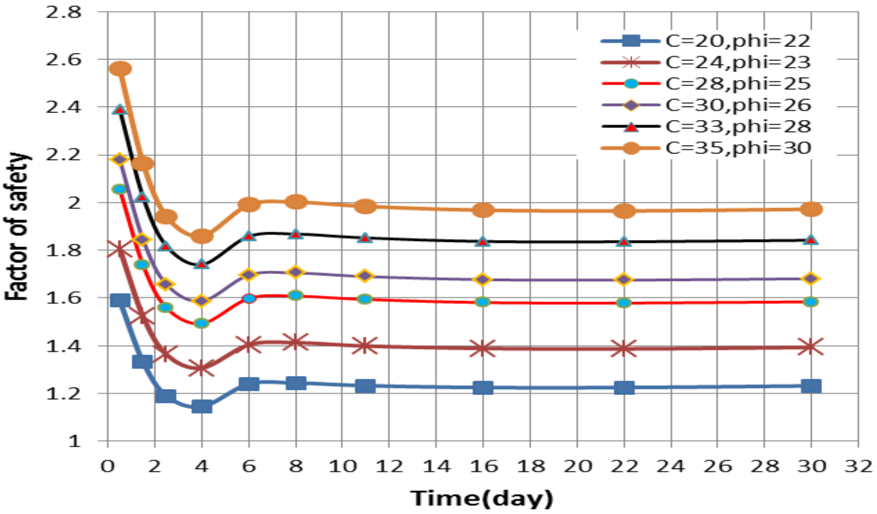


Figure (9): Factor of safety vs. time(day) at (γ=21)kN/m^3.

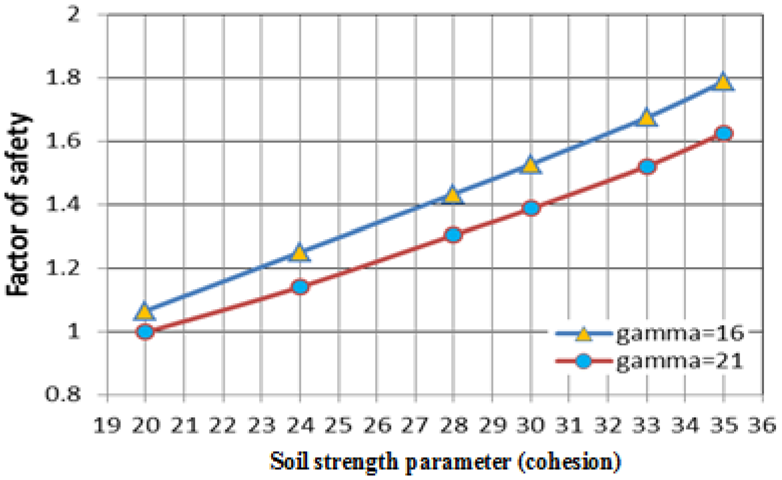


Figure (10): Factor of safety vs. soil strength parameter (cohesion)at(γ=16 and 21)kN/m^3

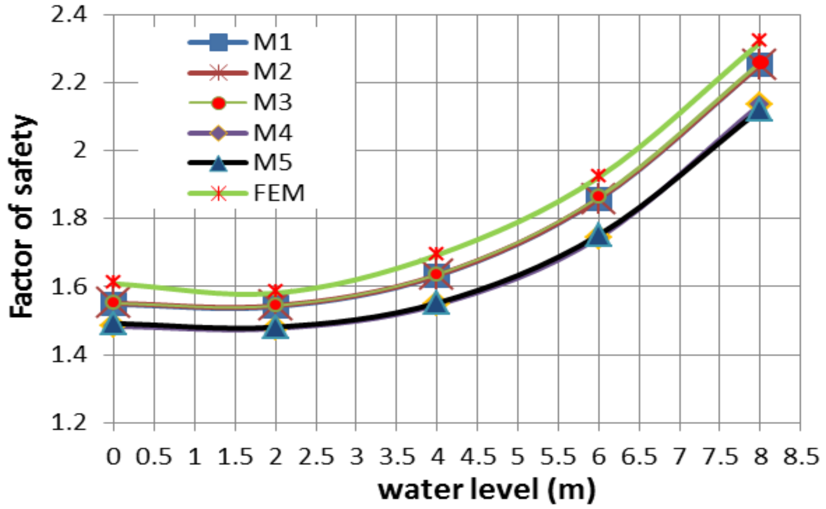


Figure (11): Factor of safety vs. water level for different methods.

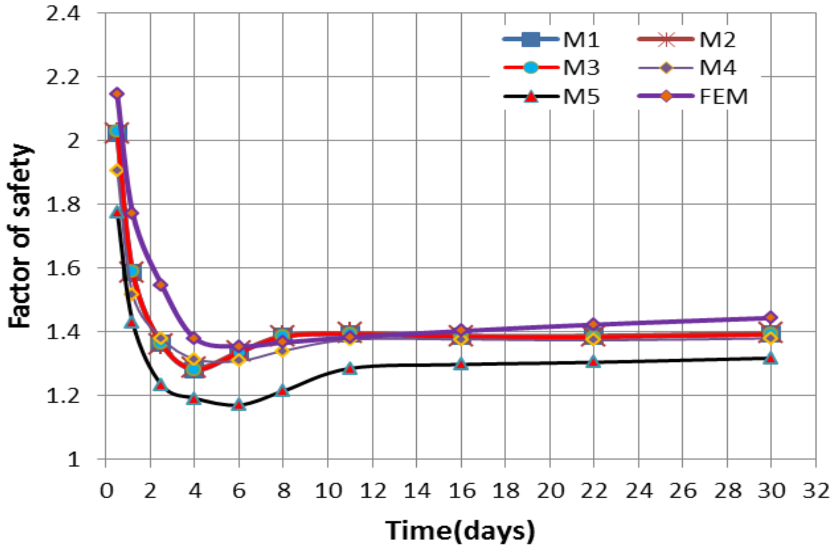


Figure (12): Factor of safety vs. time(days) for different methods.

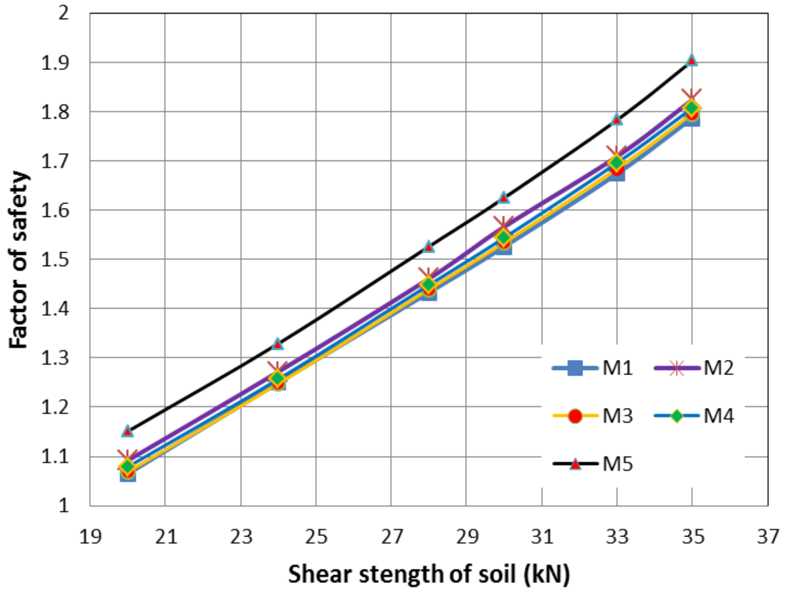


Figure (13): Factor of safety vs. shear strength of soil for different methods.

تحليل استقرارية المنحدر لسد ترابي

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الخلاصة

ان دراسة استقرارية المنحدر مهمة في تصميم وانشاء السدود الترابية تحت تأثير الهزات الارضية وبعض الاحمال الاضافية. بعض العوامل تؤثر على استقرارية منحدر السد الترابي مثل تغير مستوى الماء في الخزان او النزول السريع لمستوى الماء. في الدراسة الحالية تم استخدام طرق التوازن الحدي والعناصر المحدودة لحساب عامل الامان للسد الترابي. ان الهدف الرئيسي يتمثل بدراسة تأثير معاملات التربة والتي تشمل(تماسك, زاوية الاحتكاك الداخلية, وحدة وزن التربة) على قيم عامل الامان لمنطقة واجهة السد الترابي. حيث اظهرت النتائج ان قيم عامل الامان تزداد عندما معاملات التربة(تماسك, زاوية الاحتكاك الداخلية) ومستوى الماء يزداد وحدة وزن التربة يقل. وقيم عامل الامان تقل بسرعة في حالة النزول السريع لمستوى الماء. ويمكن ان نستنتج ان استقرارية السد الترابي تزداد عندما معاملات التربة(تماسك, زاوية الاحتكاك الداخلية) تزداد وحدة وزن التربة يقل مع زيادة مستوى الماء في الخزان وربما يتعرض السد الترابي للانهيار في حالة النزول السريع لمستوى الماء.