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SEEPAGE AND SLOPE STABILITY ANALYSIS OF LEVEES SUBJECTED TO FLOODING (THEORITICAL STUDY)

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Abstract: In this study, a levee is modeled by using ANSYS 11.0 to be analyzed for seepage and slope stability. One of the main causes of levees failure is the destabilizing effect of seepage forces of the infiltrating water during floods. The existence of the analogy between seepage and heat diffusion made it possible to analyze the hydraulic problem with ANSYS/THERMAL. In addition, the slope stability is analyzed for different cases by Strength Reduction Finite Element Method. The results showed that strength reduction technology was suitable for simple homogeneous side slope stability analysis. To verify the accuracy of the analysis, the results are compared with a case that studied by finite element program SEEP/W and SLOPE/W (GEOSLOPE 2007) has been taken and modeled by ANSYS/APDL. The results showed close to them for seepage and slope stability analysis. In other hand, some parameters such as flood conditions, permeability, slopes, and soil parameters (cohesion and angle of internal friction) are taken to study there effects on the seepage and slope stability. It is found that, the steep slope for cohesion less soil in high flood level is the most critical section of levees for both static and seismic load. Moreover, hydraulic behavior of clay core in a levee section subjected to flooding is investigated with help of numerical modeling. It was observed that a clay core can ensure reduction in pore water pressures and ensure adequate slope stability to the levee section.

Keywords: *Levees, ANSYS/THERMAL, Strength Reduction Finite Element Method, Seepage, Slope Stability.*

تحليل التسرب واستقرارية المنحدر للحواجز الترابية المعرضة للفيضانات

الخلاصة: في هذه الدراسة تم نمذجة حاجز ترابي بواسطة برنامج ألأنسز (ANSYS) 11.0 لتحليل التسرب واستقرارية المنحدر. إن أحد اسباب فشل الحاجز الترابي هو تاثير عدم الأستقرارية الناتجة من قوى التسرب للمياه المترشحة خلال الفياضانات . ان وجود التشابه بين التسرب وانتشار الحرارة يعطي امكانية لتحليل المسالة الهيدروليكية بواسطة الانسز/الحرارة. تحليل استقرارية المنحدر لحالات مختلفة بواسطة طريقة تخفيض مقاومة العنصر المحدد، بينت النتائج بان تقنية تخفيض المقاومة كانت ملائمة لتحليل استقرارية المنحدر الجانبي المتجانس البسيط. من اجل التحقق من دقة التحليل تم مقارنة النتائج من خلال حالة تمت دراستها بواسطة برنامج العنصر المحدد SEEP/W و SLOPE/W (GEOSLOPE 2007) والتي تم عمل موديل منها بواسطة الانسز. بينت النتائج تقارب للتسرب و استقرارية المنحدر . من ناحية اخرى بعض المعاملات مثل ظروف الفيضان، النفاذية ، الميول و معاملات التربة (التماسك وزاوية الاحتكاك الداخلي) قد اخذت لدراسة تاثيرها على التسرب و استقرارية المنحدر. لقد وجد بان المنحدر حاد الميل للترب العديمة التماسك عند مستوى الفيضان العالي هي غالبا المقطع الحرج للحواجز الترابية لكلاً من الاحمال الستاتيكية والديناميكية. اكثر من ذلك فان التصرف الهيدروليكي للب الطيني لحاجز ترابي معرض للفيضان قد تحقق بمساعدة الموديل العددي. لقد تم ملاحظة بان اللب الطيني يمكن ان يضمن تخفيض في ضغط المسام و يضمن استقرارية لمنحدر ملائمة لمقطع الحاجز الترابي.

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1. Introduction

Levees are earthen embankments which protect the land side area during floods. They play a key role to protect areas which are in the vicinity of rivers.

As all these structures are having almost identical cross-section, a typical earth dam or a levee section is considered in this study. Mostly, the failure of embankment is as the consequences of cutting by the public, overflow, erosion, seepage and sliding [1].

One of the most dangerous problems in designing the levee section is seepage of water through the layers of the levee that in touch with water in landward side. Various failures such as excessive hydrostatic pressures beneath an impervious top stratum on the landside, piping beneath the levee itself, and sand boils may be occurred in the absence of seepage control measures [2]. Some of principle for seepage control measures are provision of some control devices such as landside seepage berms, cutoff trenches, pervious toe trenches, riverside impervious blankets, interceptor drains, and pressure relief wells.

This paper are taken into account the stability and seepage analysis of a levee section which is analyzed using ANSYS 11.0 software and the results of analysis have been verified with (GEOSLOPE 2007) software. For comparison purposes, a levee section with clay core is considered. In other hand, some parameters such as flood conditions, permeability, slopes, soil parameters, and load conditions are taken to study there effects on the seepage and slope stability.

2. Methods Of Analysis by ANSYS

2.1Finite element by ANSYS

ANSYS is a one famous commercial finite element analysis system software. It is useful to analysis and solve the complex problem that need to serve time consuming and to be more accurate. Other software concerning finite element; namely; SEEP/W and SLOPE/W. SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium. Software tools such as SEEP/W do not inherently lead to good results [3].

The difference among them that ANSYS is multi option software. It can analyzes different features in the structure at the same time as compared with other one that specific mostly in only one feature. Moreover, it has verifications in its manual to give more confidence to the users.

2.2Slop Stability Analysis

The slice and numerical methods are the common methods of the slope stability analysis which they mainly depended on the limit of equilibrium and elastic-plastic theories, respectively [4,5]. In between those two methods, the limit equilibrium method is a more traditional and mature method for the slope stability analysis. This is mainly includes the (Spencer, Fellenius, the Bishop, the Janhu method, and the slide wedge , ect.) methods [6,7].

Nowadays with developing of the computer technology and calculating methods, the finite element method is widely adopted in the slope stability calculation among other numerical methods [8].

In this study, two dimensions (2D) slope stability model will be analyzed. The elastic-plastic large deformation finite element method (FEM) will be adopted. Moreover, the strength reduction technology combined with convergence criterion, and plastic zone penetrability criterion will be used.

The self-weight or external load function is a specific factor in the analysis of slope stability in the case of slope failed to maintain itself. In this case, the slope plastic zone would cover the whole slope and thus form slide band [9].

The calculations for the slip surface by finite element are combined with the soil that slips with this slip surface [10,11]. In this case, the Strength Reduction Factor (SRF); F of finite element method is firstly set as an initial strength reduction coefficient and then constantly adjust shear strength parameters of soil mass using (SRF). This factor is applied on the shear strength τ_f. Therefore, the allowable shear stress is calculated as the shear strength is divided by this factor.

The Coulomb-Mohr shear strength could be given by:

$$\tau_f = c + \sigma \tan\emptyset \quad (1)$$

Where: τ_f is defined above, while c, σ, and $\emptyset$ are cohesion, normal stress, and angle of internal friction of soil; respectively.

The allowable shear stress is calculated as:

$$\tau = \frac{\tau_f}{F} = \frac{c}{F} + \sigma \frac{(\tan\emptyset)}{F} \quad (2)$$

Where: F is the factor of safety that should be available for the soil slop stability.

If the reduced parameter values; defined bellow; have been used, it will still has the same Coulomb-Mohr equation for shear strength.

$$\acute{c} = c/F \quad (3)$$

$$\acute{\emptyset} = \arctan(\tan\emptyset/F) \quad (4)$$

Where: $\acute{c}$ and $\acute{\emptyset}$ are soil strength parameters for cohesion and angle of internal friction; respectively.

These parameters given in (3) and (4) will consider as the material parameters input into a finite element software program. Therefore, the stresses remain safe because the program will restrict the shear stresses under these reduced shear strength parameters.

The mechanism of slope stability failure of the levees depends on SRF (F) ; if the reduction went on; slope would become unstable and failure would occur. During the numerical process, F is varied and as it is increased, shear strength parameters (i.e.,$\acute{c}$ and $\acute{\emptyset}$) are decreased; then slope deformation gradually increased and slope stress and strain distribution began to change. After that, the slope condition gradually reached limit equilibrium from safe state.

2.3Seepage Analysis

One of the most important problems in designing the levee section is to control seepage of water.

Seepage analysis at ANSYS software has been done based on thermal methods, it made possible due to the existence of the analogy between the equations of seepage flow and the equations of the heat diffusion.

Mass and continuity equation seepage model are as below [12]:

$$\frac{\partial}{\partial x}\left[k_x \frac{\partial p}{\partial x}\right] + \frac{\partial}{\partial y}\left[k_y \frac{\partial p}{\partial y}\right] + \frac{\partial}{\partial z}\left[k_z \frac{\partial p}{\partial z}\right] + q = \mu_s \frac{\partial p}{\partial t} \qquad (5)$$

In which:

k_x, k_y, k_z are permeability coefficient at x,y,z direction respectively.

q: Discharge (for source/sink).

p: Fluid head.

μ_s: Reservoir capacity.

Thermal-steady continuity condition, at ANSYS software are as below:

$$\frac{\partial}{\partial x}\left[k_x \frac{\partial T}{\partial x}\right] + \frac{\partial}{\partial y}\left[k_y \frac{\partial T}{\partial y}\right] + \frac{\partial}{\partial z}\left[k_z \frac{\partial T}{\partial z}\right] + \rho Q = \rho c \frac{\partial T}{\partial t} \qquad (6)$$

In which:

T: is the temperature, ρ: is the mass density, c:is the specific thermal coefficient, and k_x, k_y, k_z: is thermal conductivity. Thermal index at different x,y,z are density at thermal resource.

In this comparison, ρ is substitute with T at Thermal equation. μ_s is substitute at ρc, q which are similar Q.

3. Case Study

To validate the efficiency of ANSYS programing in seepage and slope stability analysis problems, the methods of analysis by ANSYS is applied on the levee taken from [13], as shown in Fig. 1.

The levee section has length L of 28.5 m, height of 5 m, crest width 6m, water side slope was assumed to be 1V:2.5H and landside slope was assumed as 1V:2H. The foundation material was assumed to have 5m thickness below the levee section.

Shear strength parameter and values of permeability for the levee, foundation are presented in Table 1.

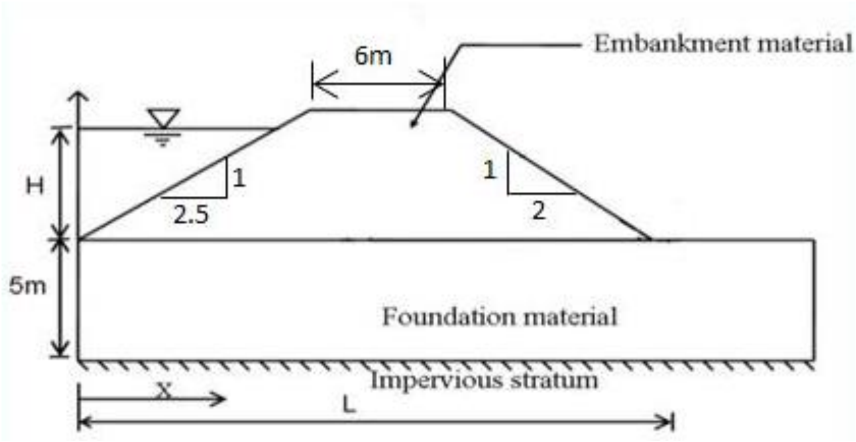

Figure 1. Geometry of a levee section [13]

Table 1. Properties of levee and foundation materials [13]

Sr. No.	Properties	Levee and foundation material
1	Unit weight; γ (kN/m^3)	16.43
2	Cohesion C ;(kPa)	11.6
3	Friction angle ∅; degree	27
4	deformation modulus E ; (mPa)	40
5	Poisson's ratio; υ	0.35
6	Coefficient of permeability k ; (cm/sec)	1 x 10^{-6}

4. Numerical Simulation by using ANSYS

The finite element program ANSYS 11.0 is used to simulate seepage and slope stability for the assumed levee section. In seepage analysis approach, ANSYS/THERMAL model was adopted in simulation by using 2D 8-Node Thermal Solid element (PLANE77) as shown in Fig. 2. The initial and final position of the water level in the levee must be prescribed. A number of trails were performed to obtain a suitable mesh configuration.

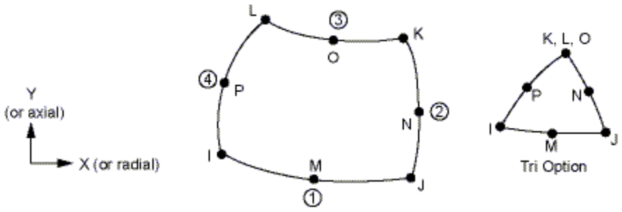

Figure 2. PLANE 77 Element Geometry [14]

Soil mass is assumed to be incompressible and saturated for the sake convenience. As levee is subjected to flood thus seepage is modeled for High Flood Level (HFL) to simulate most severe situation at steady state condition.

Consequently, slope stability analyses were performed by 2D 8–Node Structural Solid element (PLANE 82), which similar to PLANE77 element in geometry, for HFL = 4 m. A series of numerical experiments were performed in order to get the minimum factor of safety *(FS)* according to strength reduction finite element method. For this problem, the horizontally constrained of boundary condition was for the right and left sides of the foundation; while it was completely fixed at the bottom side. In other hand, it more seriously to implies the load in the analysis of slope stability of levees; where the external loads are the gravity and lateral water pressure.

5. Results of Analysis and Discussion

5.1Seepage Analysis

According to Table 1, levee section is modeled. This section is simulated for HFL=4m at steady seepage condition using finite element ANSYS Software and compare the results with the SEEP/W software in [13]. Fig. 3 and Fig.4 a, b show pore water pressure contours for SEEP/W and ANSYS software, respectively.

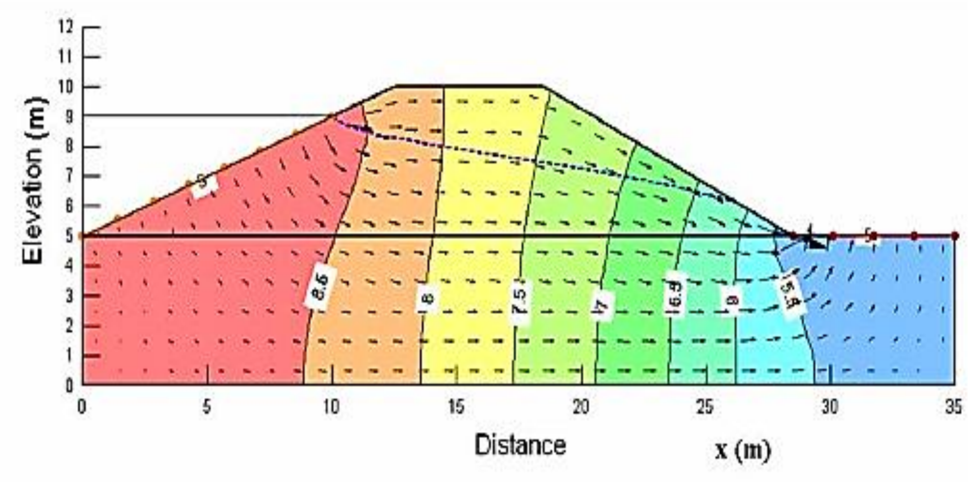

Figure 3. Pore water pressure contours by SEEP/W software [13]

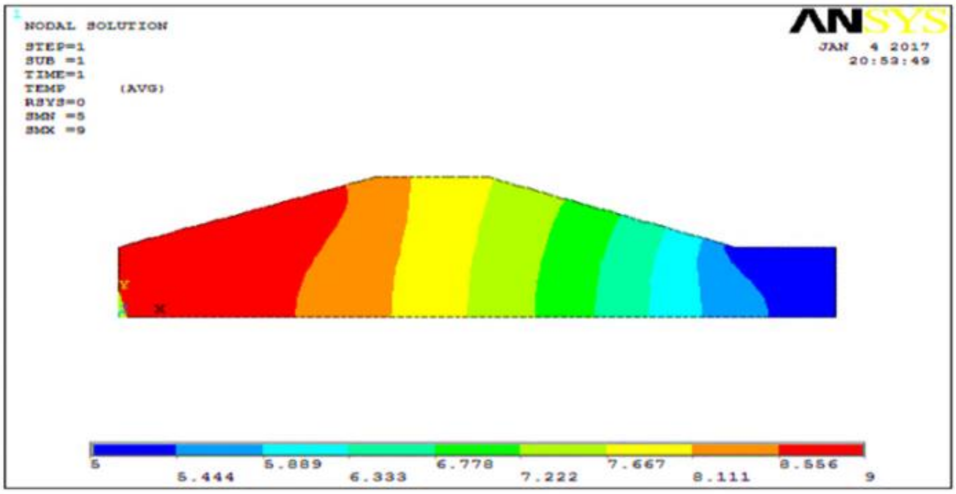

Figure 4 (a). Pore water pressure contours by ANSYS software (equipotential lines)

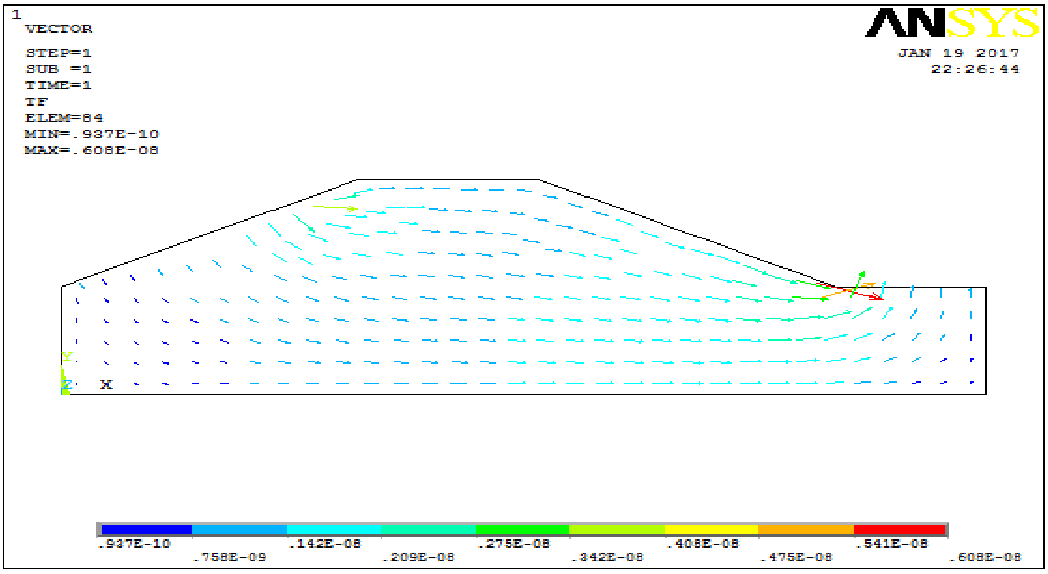

Figure 4 (b). Pore water pressure contours by ANSYS software (flow lines).

Results showed in Figs. 3 and 4 proved the efficiency of ANSYS software in seepage analysis of levees, this due to the convergences between the results of the ANSYS and SEEP/W software for the same case studied.

5.2Slope Stability Analysis

For same section and according data from Table 1, stability analyses were performed via ANSYS software based on strength reduction finite element method with HFL = 4 m. The results of analyses will be compared with the stability analyses which based on SLOPE/W software by using Bishop's method of slices in [13], as shown in Figs. 5 and 6.

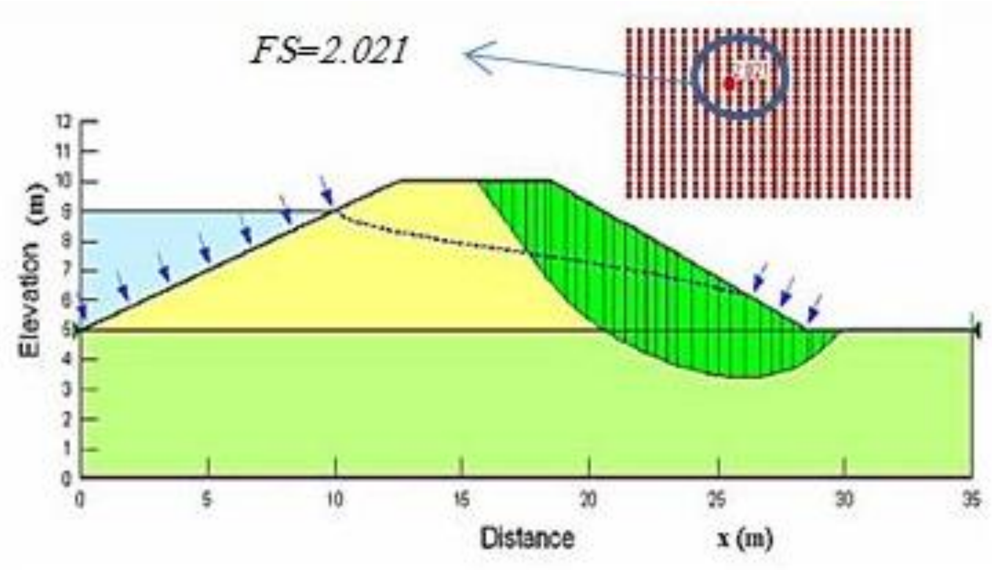

Figure 5. Stability analyses by SLOPE/W software [13]

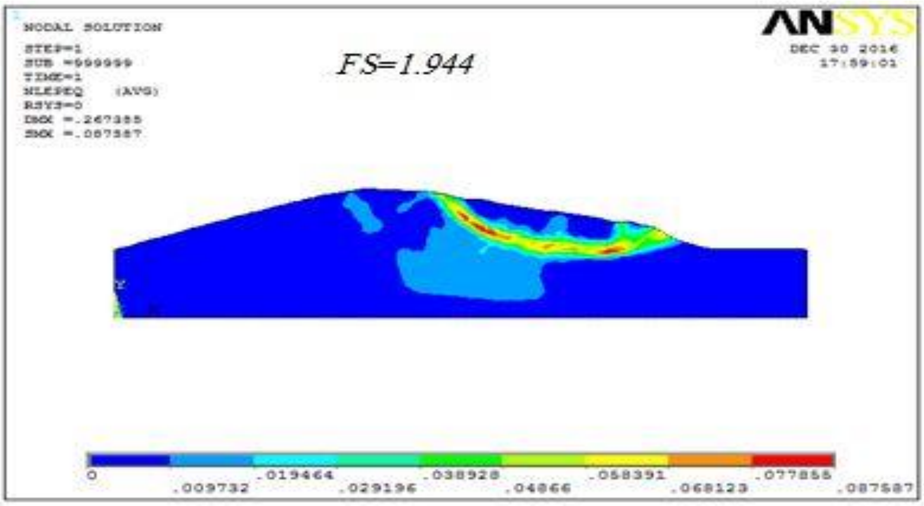

Figure 6. Stability analyses (equivalent plastic strain) by ANSYS software

From Figs. 5 and 6 above, it is proved that the analyses by both of ANSYS and SLOPE/W software gave good close results, where the factor of safety *(FS)* of the slope stability by ANSYS is1.944 while, it is equal to 2.021 when SLOPE/W software be used.

5.3The Parametric Study

In this section the parametric study has been considered to give some reality about subject, therefore:

- *FS* is calculated for three different slopes with three different flood conditions (Dry, Low Flood Level *LFL*, and High Flood Level *HFL*) conditions [15], where the type of soil is considered as $(\mathrm{C} = 30\mathrm{kPa}, \emptyset = 34°, \gamma_t = 17.5\mathrm{kN/m^3})$. The results of *FS* are presented in Table 2.

Table 2. Results of stability analysis of silt soil $(\mathrm{C} = 30\mathrm{kPa}, \emptyset = 34°, \gamma_t = 17.5\mathrm{kN/m^3})$[15]

	Factor of Safety (FS)		
	Dry Condition	LFL=1m	HFL=4m
Slope			
1:1	1.85	1.65	1.46
1:1.5	2.14	1.96	1.93
1:2	2.26	2.10	2.08

In other hand, the soil properties are selected as given in [16]. The results of *FS* are calculated as given in Tables 3 and 4.

Table 3. Results of stability analysis of cohesion less soil $(\mathrm{C} = 0\mathrm{kPa}, \emptyset = 30°, \gamma_t = 16\mathrm{kN/m^3})$ [16]

	Factor of Safety (FS)		
	Dry Condition	LFL=1m	HFL=4m
Slope			
1:1	0.91[a]	0.93[a]	0.92[a]
1:1.5	1.12[b]	1.17[b]	1.14[b]
1:2	1.37	1.39	1.42

[a.] Failed in slope stability *FS*<1

[b.] Lower than allowable limit of *FS*.

Table 4. Results of stability analysis of sandy clay soil ($C = 14\mathrm{kPa}, \emptyset = 26°, \gamma_t = 14.5\mathrm{kN/m^3}$) [16]

Slope	Factor of Safety(FS)		
	Dry Condition	LFL=1m	HFL=4m
1:1	1.82	1.06	1.02[b]
1:1.5	2.04	1.38	1.28
1:2	2.24	1.57	1.52

[b] Lower than allowable limit of *FS*.

The failure of soil mostly depends on *FS*. The required *FS* is preferable to be greater than 1.2 [15]; therefore, the lesser value would result in a threat for soil. After analysis, *FS* for cohesion less soil at all conditions with slope 1:1 are found significantly less than one, while for slope 1:1.5 is less than the required value (i.e., 1.2). Also, *FS* for sandy clay soil at high and low flood condition for slope 1:1 is less than 1.2.

- *FS* under seismic load is concerned as time-history force as shown in Fig. 7 for silt soil properties given in Table 2 (i.e. $C = 30\mathrm{kPa}, \emptyset = 34°, \gamma_t = 17.5\ \mathrm{kN/m^3}$) in high flood level be compared with static load, is presented in Table 5.

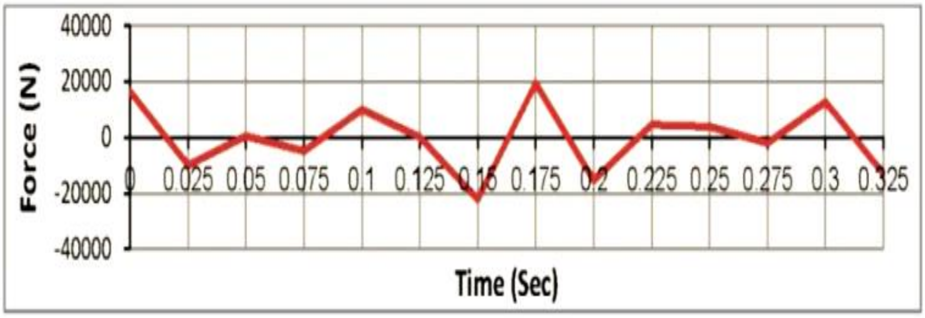

Figure 7. Seismic time-history force [17]

Table 5. Factor of safety comparison between static and seismic loads.

Slope	Factor of Safety(FS)	
	Under static load	Under seismic load
1:1	1.46	0.78[a]
1:1.5	1.93	1.18[b]
1:2	2.08	1.31

[a] Failed in slope stability *FS*<1.
[b] Lower than allowable limit of *FS*.

The seismic load produces the horizontal forces acting on the slices that increasing the moment of the weight of the slices with respect to the center of the slip circle, thus reducing *FS* as represented in Table 5.

- Maximum seepage flow was calculated for five different of soil permeability ($k\ (m/\mathrm{sec})$) with another three different flood levels (*FLs*) as given in Table 6.

Table 6. Results of maximum seepage flow for different k and FLs

	Max. seepage flow ($m^2 sec^{-1}/m$)		
FLs / K m/sec	4m	3m	1m
0.01	0.018619	0.01439	0.004563
$1*10^{-3}$	0.002183	0.001685	$0.441*10^{-3}$
$1*10^{-5}$	$0.0186*10^{-4}$	$0.155*10^{-4}$	$0.441*10^{-5}$
$1*10^{-6}$	$0.0186*10^{-5}$	$0.144*10^{-5}$	$0.445*10^{-6}$
$1*10^{-8}$	$0.0186*10^{-7}$	$0.155*10^{-7}$	$0.445*10^{-8}$

Table 6 indicates that, there is a direct relationship between the maximum seepage flow with both permeability and flood level, where increasing them will directly increasing maximum seepage flow.

5.4Levee with Core

A clay core may be considered as a control device to reduce seepage through the embankment. This can be trenched into the foundation to reduce seepage underneath the embankment. To define the effect of core on seepage and stability analysis, levee section taken from [18] is modeled by ANSYS software, as shown in Fig. 8.

According to geometry of levee in Fig. 1, data in Table 1, and core section in Fig.8 which have parameters are unit weight (γ_s=18kN/m^3), Internal friction ($\varphi=0^0$), Cohesion (C=40 kN/m^2), and permeability ($k = 1 * 10^{-9}$ cm/sec), the final results of seepage and stability analysis are shown in Figs. 9, 10, and 11.

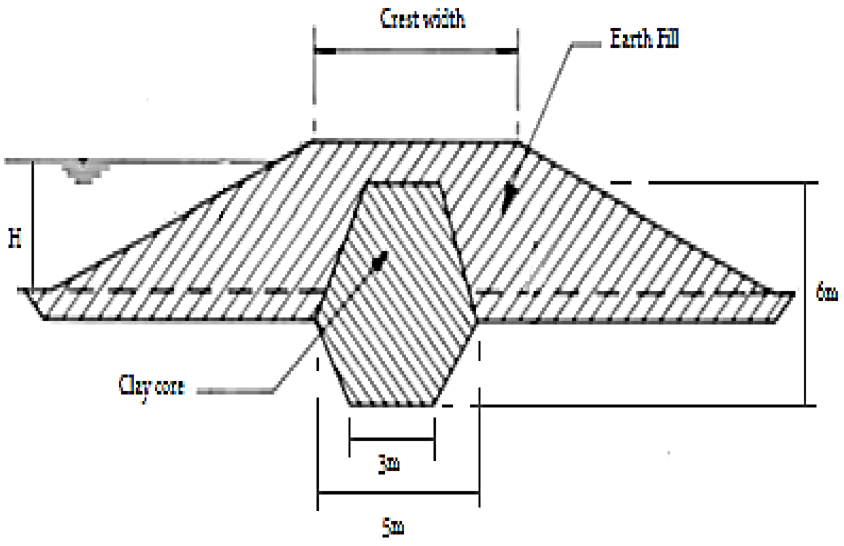

Figure 8. Levee section with clay core [18]

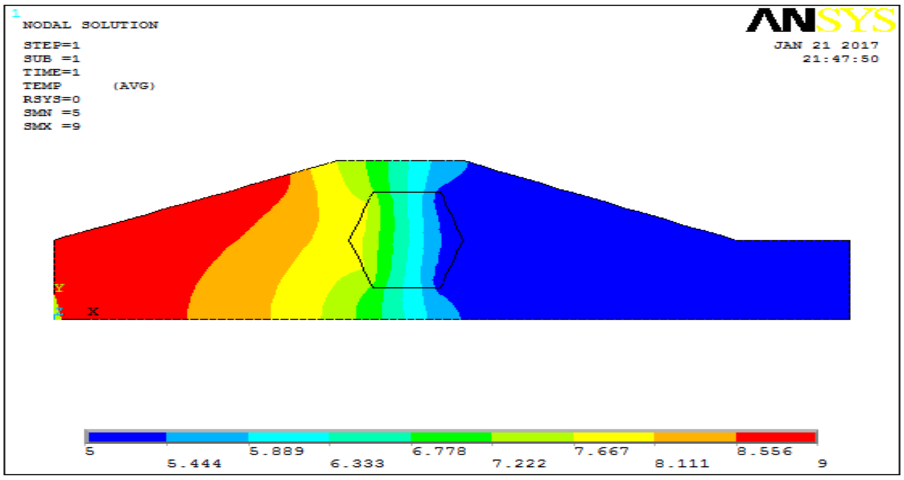

Figure 9. Pore water pressure contours (equipotential lines) for levee with core

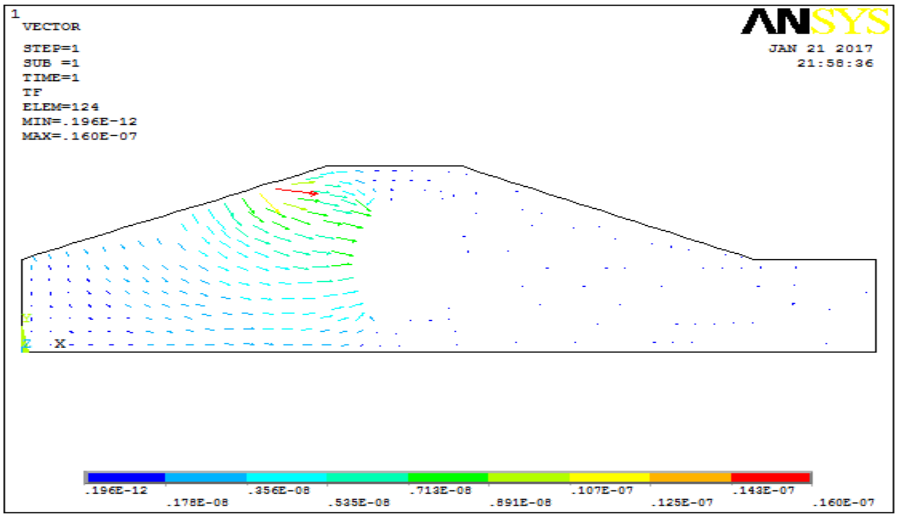

Figure 10. Seepage flow vector (flow lines) for levee with core

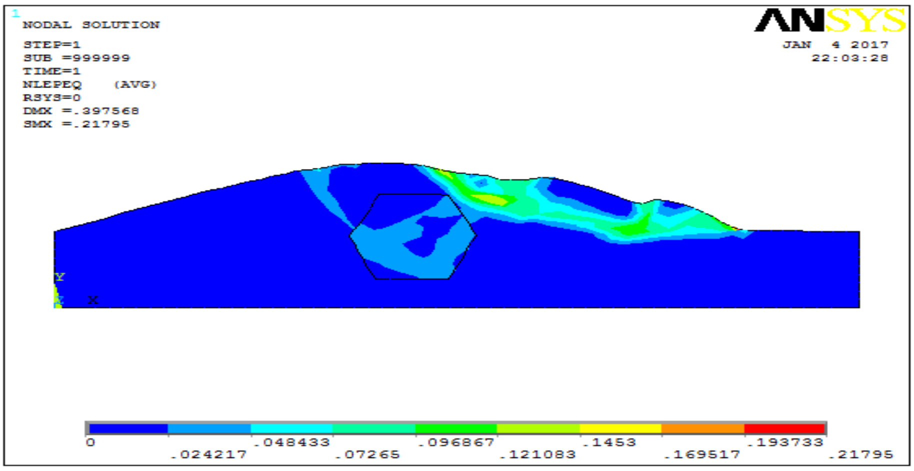

Figure 11. Stability analyses (Equivalent plastic strain) for levee with core

From investigating the hydraulic behavior of clay core for a levee section subjected to flooding as shown in Figs. 9 and 10, it was observed that a clay core can ensure reduction in the pore water pressures in levee section compare with the section without core statues in Fig. 4. Also, it gave a factor of safety for slope stability larger than factor without use it, where the factor of safety from Fig. 11 was equal to 2.10, while from Fig. 6 was 1.94.

6. Conclusions

1. The ANSYS/APDL is an efficient tool to simulate and analyze seepage and slope stability problem.
2. After stability analysis, the safety factors for cohesion less soil at all conditions with slope 1:1 are found significantly less than one, while for slope 1:1.5 is less than the required value of the factor (1.2) and this similar to sandy clay soil at high and low flood condition for slope 1:1.
3. Safety factor for slope stability decreases clearly when applying seismic load at section, especially for 1:1 slope.
4. Clay core in levee section can ensure a reduction in the pore water pressure and ensure adequate slope stability to the levee section.

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7. References

1. Nuzhath, F., and Ansary, M. A. (2014). “*Slope Stability Analysis of a Jamuna River Embankment*”. Journal of Civil Engineering (IEB), Vol. 42, No. 1, pp. 119-136.
2. US Army Corps of Engineers Manual No. 1110-2-1913. (2000). “*Design and Construction of Levees*”. Washington, USA.
3. GEO-SLOPE International Ltd. (2012). “*Seepage Modeling with SEEP/W: An Engineering Methodology*”, GEO-SLOPE International Ltd.
4. Kahatadeniya, K.S., Nanakorn, P., and Neaupane, K.M. (2009). “*Determination of the critical failure surface for slope stability analysis using ant colony optimization*”. Journal of Engineering Geology, Vol.108, No. 1-2, pp.133-141.
5. Cheng,Y.M., Liu, H.T., and Wei,W.B. (2005). “*Location of Critical Three-Dimensional Non-Spherical Failure Surface by NURBS Functions and Ellipsoid with Applications to Highway Slopes*”. Journal of Computers and Geotechnics, Vol.32, No.6, pp.387-399.
6. Wei, W.B., Cheng,Y.M., and Li, L. (2009). “*Three-Dimensional Slope Failure Analysis by the Strength Reduction and Limit Equilibrium Methods Original Research Article*”, Journal of Computers and Geotechnics, Vol.36, No.1-2, pp. 70-80.
7. Duncan, J. M. (1996). “*State of the Art: Limit Equilibrium and Finite Element Analysis of Slopes*”. Journal of Geotechnical Engineering, Vol.122, No.7, pp.577-596.

8. Bo,H. and Zhang, H.(2012). "*Stability analysis of slope based on finite element method*". International Journal of Engineering and Manufacturing, Vol. 3,No. 3, PP. 70-74,.
9. Wang, Z. and Jiang, X. (2012). "*Computational Accuracy Impact Factors of Slope Stability Safety Factor and Finite Element Strength Reduction Method*". Electronic Journal of Geotechnical Engineering (EJGE) , Vol. 17 , Bund X, pp.3547-3558,.
10. Wu Ya jun.(2003). "*Numerical Analyses of Stability of Soil Slopes and Interaction of Soil and Support Structure in Foundation Pit Engineering*". Da Lian University of Technology.
11. Long, F., Xie, J., and Zhang,Y. j. (2012). "*The Strength Reduction Method for Stability Analysis of Slope Based on FLAC-3D*". China Science and Technology Information, Vol. 22, pp. 27-29.
12. Kamanbedast, A. and Delvari, A. (2012). "*Analysis of earth dam: seepage and stability using Ansys and Geo-Studio Software*". Journal of World Applied Sciences, Vol. 17, No. 9, pp.1087-1094.
13. Rishabh, S. K. and Viswanadham, B.V.S. (2011). "*Some studies on seepage analysis of levees subjected to flooding*". Proceedings of Indian Geotechnical Conference , Kochi, Paper No. N-269, pp. 915-918.
14. ANSYS. ANSYS User's Manual. (2007). "ANSYS Theory Manual". Version 11.0.
15. Mahbub, M., Binoy, T, H., and Ahmed, A. (2013). " *Slope Stability Analysis of Embankment of Jamuna River*". International Journal of Science and Engineering Investigations, Vol. 2, No. 19, pp. 93-98.
16. Awad, A. (2016). "*Geotechnical Maps for the Soil of Babylon Governorate Using Geographic Information* ". M.Sc. Thesis, Department of Civil Engineering, College of Engineering, University of Babylon, Babylon, Iraq.
17. Al-Qaisi, A.Z.M. 2016. "*Optimal Design of Concrete Gravity Dams on Random Soil*". PhD. Thesis, Department of Building and Construction Engineering, University of Technology, Baghdad, Iraq.
18. The Fluvial Design Guide (FDG2-Ch9). (2009). " *Fluvial – Design – Guide – structure* ", Environment Agency.