Stability analysis of earth dams based on construction pace on soft soil

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Abstract: The present study seeks to evaluate the effect of earth dams construction pace of soft soil on stability of its slopes. To achieve it, two types of earth dams with the same height and material characteristics and two different slopes of 1:5 and 1:2.5 were selected and evaluated through Plaxis V8 modeling software. The findings show that by increase of dam construction pace, the horizontal and vertical displacements maximize and a severe increase enhances displacements consequently.
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Key words: earth dam, finite elements, stability, slope, stages of constructions, pore water pressure, effective stress distribution, embankment,construction pace

1. Introduction

Embankments should be taken into consideration as heavy structures have a dynamically significant interaction with their underlying bed. The construction of a dam embankment on soft soil layers because of a high level of saturated water causes an increase in pore pressure in layers. In case of applying force without drainage, the resulted effective stress will decrease. Therefore, an evaluation of pore pressure changes and the amount of settlement of dam embankment performed on soft soils.

Sherard et al (1963) found that positive pore water at time of dam construction in each point of middle parts of dam core could be regarded as 50% of total pressure of earth derived from the weight of upper layers that this ratio in return could add to 80 %. In other words, for ratio of 50%, the pressure height of water (h_w) in one point might be assumed as 1.1 time of the soil height above it. Thus, using of 1.1-1.25 figures in computations of stability factor for dam body immediately after the end of construction seems logical. However, to prevent the likelihood of any error, the way the effective elements influence on this factor must be studied beforehand.

An estimation of levels of pore water pressure and their comparison to measured values in desert is principally important. This in fact gives dam designers a power to compare invented designs with reality and in each stage assess true safety factor of structure versus failure(Bishop and Blight 1963;Alonso and Battle 1998).

Fell et al (1992) concluded that in some of studies to measure pore water pressure, the prevailing relationships on failure situation has been used. In analysis of dams stability, the pore water pressures in calculations are considered with the help of "ratio of pore pressure" parameter:

$$(1) \quad r_u = \frac{u}{\gamma_0 \Delta H} = \frac{(u_0 + B\Delta\sigma)}{(\gamma_0 \Delta H)} = \frac{u_0}{\gamma_0 \Delta H} + B$$

Where, γ is the weight of material size of dam body and h is the embankment thickness above the spot.

If the primary pressure (u_0) equals zero or close to zero (e.g. the earths contain optimum humidity and compaction and humidity lower than that) will be seen as r_u=B. therefore, for a saturated earth , r_u might be one unity or less. Though, in lower humidity, generally, r_u is close to 0.5(Arg and small 1995; Kohgo and Yamashita 1998).

Mellah et al (2000) in their study on finite element method and interaction of earth and structure following Moher-Culomb found that the method is capable to determine most of mechanical parameters , interstitial stress , strain , displacement and pore pressure.

Borges et al (2004) believe that the expected maximum settlement in the end of embankment construction process on soft tissue earths exceeds other tissues that is because of a decrease in porosity percentage took place during consolidation.

Kastunen et al (2006) investigated on the stress-strain behavior of embankment over soft footing with different models in untrained conditions of construction and need time for consolidation. The obtained results show that each model varies slightly. Sari et al (2009) studied the road embankment layer to layer and by numerical modeling with finite element method came to this end that the highest settlement occurs in toe part of embankment mostly.

The pace of dam construction, distribution way of water pressure in dam , and level of compaction and saturation of earth counted as factors influencing on dam stability factor . In the present paper, how the first element i.e.; pace of dam construction affects on stability factor was studied.

2. Materials and methods

In layout of earth layers, from bottom –up,sand, peat and clay earth have been placed that the dam body is made of clay. To determine the border limit, marginal borders are considered non-permeable. In other words, the borders interaction with the surrounding is cutoff and related column has been isolated. In specifying geometrical due to symmetry of layers and embankment structure, in Plaxis software, a half of porofile is regarded.

The most momentous stage after determination of materials and geometrical is meshing of the environment.Maximization of pore pressure resulted from construction process and loading on earth layers due to meshing is graphically observant in Plaxis . The present study used meshing meidum accordingly. of course in the floor (lower border) the segregation surface and open exchange (free surface) have been taken into consideration in order to the extra water which (in case of drainage) as a result of gradual loading has been declined flows inside lower softer earth layers not to be regarded in the model.

In analysis of finite elements , segregated area and final boundaries were lucid enough , but for geotechnical problems, structure interaction analysis , and its earth bed , in general , extensive parts of support bed, material and characteristics of earth layers the structure has been located on must be included in the finite elements model.

The Plaxis software used to determine artificial boundaries for finite elements network and modeling bed of important parameters in model run. Used numerical method of infinite elements is to determine changing of earth condition based on elasticity-plasticity model. The numerical basis of equation holds deformations (integrity to model elasticity-plasticity of earth). The continuous static equilibrium equation follows the bellow relation:

(2) $\underline{\underline{L}}^T \underline{\sigma} + \underline{P} = \underline{0}$

The three dimensional matrix (Cartesian), the 6 nodes mode applied to assess derived components.

(3)

$$\underline{\underline{L}}^T = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial z} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{bmatrix}$$

P : pressure component (force element)

L^T : displacement transposed matrix

σ: effective stress component

On the other hand, an increase in leakage and hydraulic pressure gradient causes instability of marginal walls. Plaxis can calculate and processing this process and its graphical output in state of disturbance and deformation.

Avoiding these deformations of footing soil, the embankment occurred in layer form to let each layer enough time for consolidation and decline of pore water pressure. To remove excess pore pressure in order to keep structure stability, consolidation could be very helpful.

The Plaxis v8 and Mohr-Culomb were chosen as the study models. In clay earth embankments in non drainage conditions, the shear stress by increasing depth in vertical direction increases as well. The Mohr-Culomb in short term makes relatively good results, though, in long-term settlement evaluations the effects of earth creep behavior leads to decreased accuracy. The creep model of soft earth in comparison performs more accurately in long-term and provide real data accordingly.

When the distribution or decline of surplus pore pressure in saturated clay earth needs to be analyzed with time, in Plaxis the consolidation analysis option should be run. Thus, the consolidation analysis and updated mesh analysis will be used in order to water pressures and the latest stress changes must be examined nonstop. Updated mesh analysis is a sort of calculations in which large deformations come into consideration. Geometrical characteristics and used materials in Models A and B are illustrated in Fig. 1 and 2 besides Table 1.

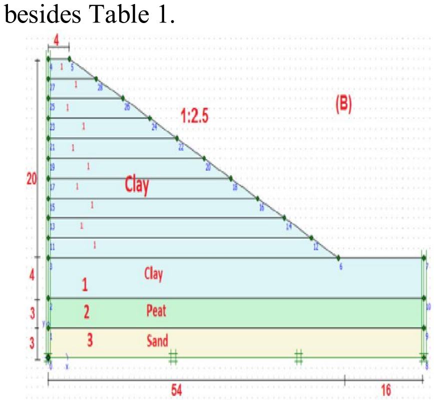

Fig. 1: geometrical characteristics of Model A

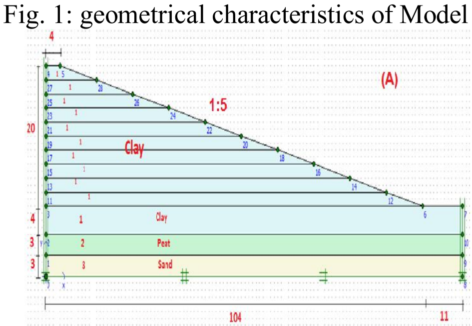

Fig. 2: geometrical characteristics of Model B

In both models, characteristics of materials and the intervals are the same. Model A with 1:5 slope and Model B 1:2.5 slope which the dam height per each model 20m and crest width is 8m have been illustrated.

Table 1: characteristics of used materials in Models A and B

3 **Sand**	**2** **Peat**	**1** **Clay**	**Unit**	***Mohr-Coulomb***
Drained	Underained	Underained		**Type**
17.00	8.00	16.00	]kN/m^3[	**unsat**
20.00	11.50	18.00	]kN/m^3[	**sat**
1.000	0.010	0.001	]m/day[	**kx**
1.000	0.001	0.001	]m/day[	**ky**
1.000	1.000	1.000	[-]	**einit**
1E15	1E15	1E15	[-]	**ck**
20000.000	500.000	2000.000	]kN/m^2[	**Eref**
0.300	0.350	0.350	[-]	
7692.308	185.185	740.741	]kN/m^2[	**Gref**
26923.077	802.469	3209.877	]kN/m^2[	**Eoed**
1.00	7.00	2.00	]kN/m^2[	**cref**
35.00	20.00	24.00	[°]	
0.00	0.00	0.00	[°]	

3. Implementation of model and conclusion

In the present paper, the examined earth dam was a no-core short earth dam with 20m height and 8m crest width following two models A and B with 1:5 and 1:2.5 slopes.

The embankment constructed from 10 layers each one had 2m thickness with construction time of 5 days in Plaxis . In order to create the initial dam stress, by exerting some specific gravity and calculation procedures, the values of stress resulted from weight achieved.

In order to run the model, layered phasation produced and amount its stress and strained obtained. According to time of dam embankment, a construction schedule firstly prepared. In this schedule for each model a 2m thickness, and 5 days time selected. Since after construction of every layer the consolidation process sounds vital a 240 day consolidation time considered because in this time span the pore water pressure would be evaluated more efficiently.

To speed up dam construction the consolidation time decreased from 240 to 50 days. In either model similar geometrical characteristics defined and static loading took place according to stability level of water table. The created models by Plaxis were evaluated based on Table 2.

Table 2: creation of examined models in Plaxis

Model (B) slope 1:2.5 Increase of construction pace		**Slope 1:5 Model (A)** Increase of construction pace		
B-2	**B-1**	**A-2**	**A-1**	**Model**
50 days	**240 days**	**50 days**	**240 days**	Consolidation time
5 days	**5 days**	**5 days**	**5 days**	Time per each layer consolidation
2 m	**2 m**	**2 m**	**2 m**	Layer thickness

To construct Models A and B, as Table 2 shows two sub models i.e.; (A-1and A-2) and (B-1 and B-2) determined. In A-1 and B-1 sub models, the consolidation time for 2m layer reduced to 240 days and in A-2 and B-2 to 50 days. Construction of the first layer in A-1,A-2,B-1 and B-2 models with Plaxis are shown in Tables 3 and 4.

Table 3: construction of the first layer in A-1 and B-1 with Plaxis

Identification	phase no.	start from	calculation	loading input	time
Initial phase	**0**	**0**	**N/A**	**N/A**	**0.00…**
<Phase 1>	**1**	**0**	**Consolidation(UM+)**	**Staged construction**	**5.00…**
<Phase2>	**2**	**1**	**Consolidation(UM+)**	**Staged construction**	**240**

According to Table [3] , phasation of first layer construction in A-1 and B-2 models with 240 day consolidation time is shown in Plaxis.

Table 4: construction of the first layer in A-2 and B-2 models in Plaxis

Identification	phase no.	start from	calculation	loading input	time
Initial phase	**0**	**0**	**N/A**	**N/A**	**0.00…**
<Phase 1>	**1**	**0**	**Consolidation(UM+)**	**Staged construction**	**5.00…**
Phase2>	**2**	**1**	**Consolidation(UM+)**	**Staged construction**	**50… <**

Table [4] indicates phasation of first layer construction in A-2 and B-2 models with 50 day consolidation time is shown in Plaxis. After describing materials and boundary conditions, the detailed results and output of Plaxis could be available from calculation menu. The vertical and horizontal displacement results for model A-1 and after 240 days layers consolidation are present in Fig. 3 and 4.

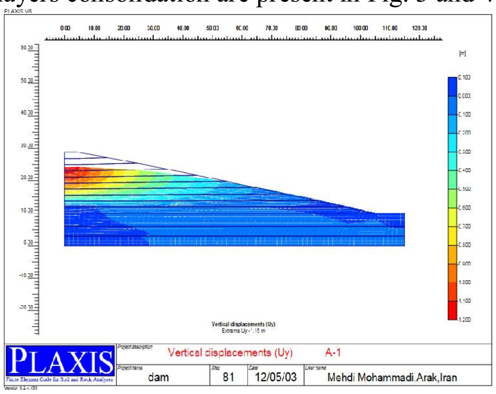

Fig. 3: vertical displacement of model A-1 after 240 days consolidation of layers

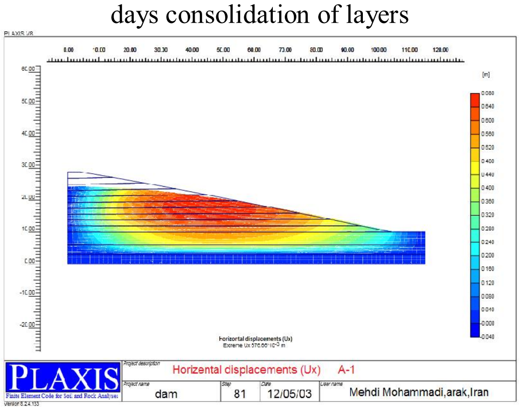

Fig. 4: horizontal displacement of model A-1 after 240 days consolidation of layers

According to the fig.3 and 4, the highest vertical displacement (settlement) under the influence of 240 days consolidation, on dam crest measured as 1.2m and horizontal displacement (X) 0.68m . Additionally, the highest raising in dam toe recorded as 0.1m that was due to undrained behavior. To assess increase rate of general displacement changes it was clear that failure mechanism is developing. Since footing of dam is made of soft earth and water level is also high, upper layers weight on central dam 0.1m raising has been observed on footing earth part. The vertical and horizontal results of displacement in model A-2 after 50 days consolidation could be seen in Fig. 5 and 6.

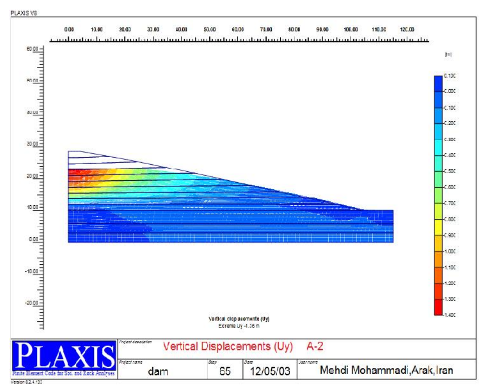

Fig. 5: vertical displacement of model A-2 after 50 days of consolidation

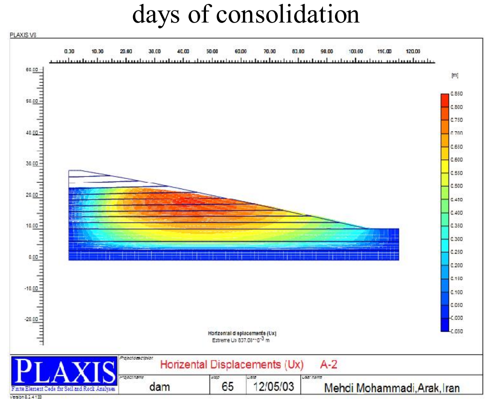

Fig. 6: horizontal displacement of model A-2 after 50 days of consolidation

As Fig.5 and 6 shows under the influence of 50 days of consolidation, the maximum rate of vertical displacement changes (settlement) found to be about 1.4m and the maximum horizontal displacement recorded as 0.85m. This level of vertical and horizontal displacement might be as a result of pace of embankment construction. In addition, by increasing pace of embankment the raising becomes zero or near zero in dam toe. Soon after layers consolidation an excess pore pressure resulted from consolidation remain inside the layer that the amount of less than $1\ {KN}/{M^2}$ measured to be safe. Thereby, the settlement of main earth and embankment has been significantly enhanced in last phase. This could be due to excess pore pressure decline which in turn leads to consolidation of earth. Fig.7 and 8 present distribution of remaining excess pore pressure after consolidation in models (A-1) and (A-2).

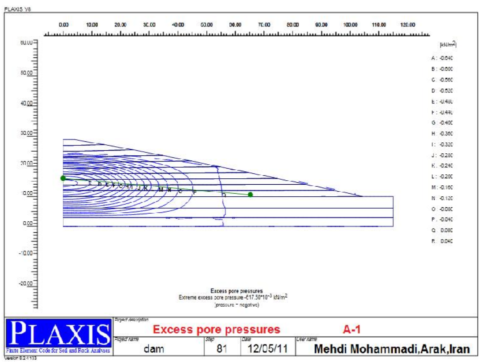

Fig. 7: excess pore pressure counter after 240 dats of consolidation in model A-1

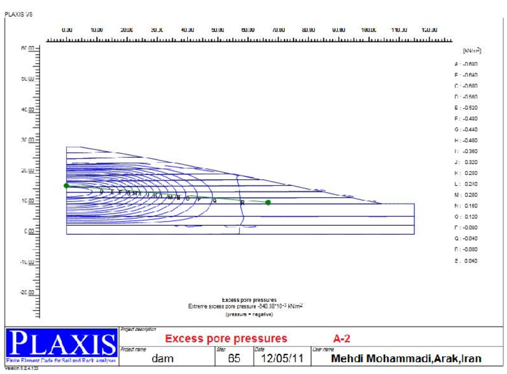

Fig. 8: excess pore pressure counter after 50 dats of consolidation in model A-2

According to counters in Fig.7 and 8 , excess pore pressure experinced after consolidation in which the maximum rate in models (A-1) and (A-2) is less than $1\ {KN}/{M^2}$. The results for vertical and horizontal displacement of model B-1 after 240 days of consolidation shown in Fig.9 and 10.

According to Fig. 9 and 10, the maximum vertical displacement (settlement) after 240 days of consolidation in dam crest was about 1.6m and for horizontal displacement (x) as 1.2m. The highest raising in dam toe found to be 0.3m that is due to slope increase. Therefore, through evaluation of general displacement increases the observation of failure mechanism than slope 1:5 develops in such an extent. Thus, the possibility of up lift under the influence of increase of slope, enhance in dam toe. The vertical and horizontal displacement results for model B-2 after 50 days of consolidation presented in Fig. 11 and 12.

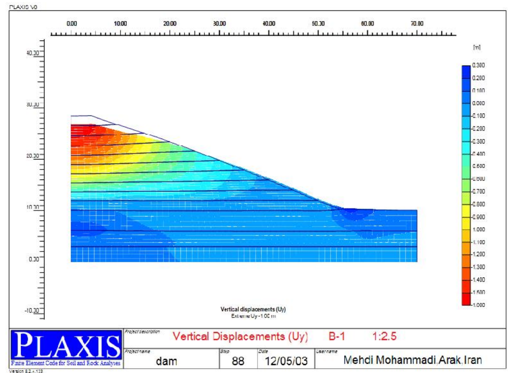

Fig. 9: vertical displacement of model B-1 after 240 days of consolidation

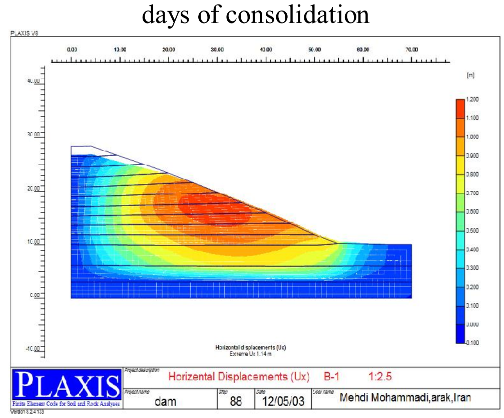

Fig.10: horizontal displacement of model B-1 after 240 days of consolidation

Fig.11: vertical displacement of model B-2 after 50 days of consolidatio
(Omit)

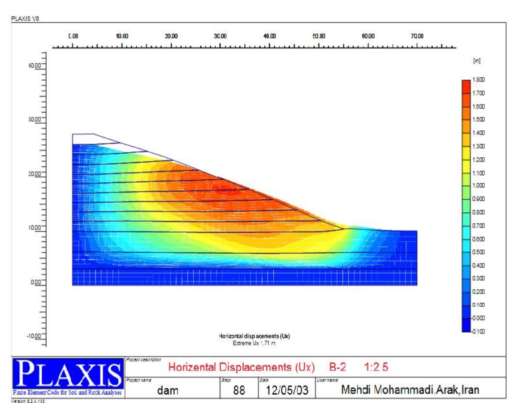

Fig.12: horizontal displacement of model B-2 after 50 days of consolidation

According to Fig. 11 and 12, the maximum vertical displacement (settlement) after 50 days of consolidation was 2.2m and for horizontal displacement (x) as 1.8m .this increase of displacement either vertically or horizontally occurs as a result of pace of embankment construction. It is evident then the settlement of main earth and embankment outstandingly enhances in last phase. This in turn is because of declining excess pore pressures which cause consolidation of the earth. Fig.13 ad 14 show the distribution of remaining excess pore pressure after consolidation in models B-1 and B-2.

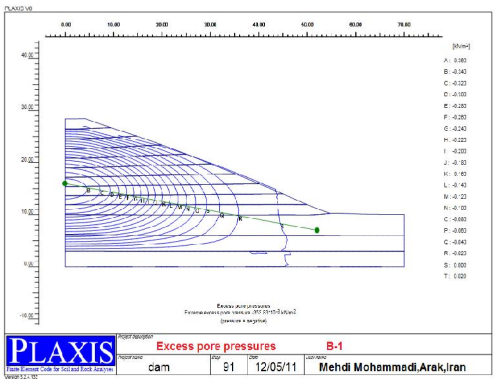

Fig.13: counter of excess pore pressure after 240 days of consolidation

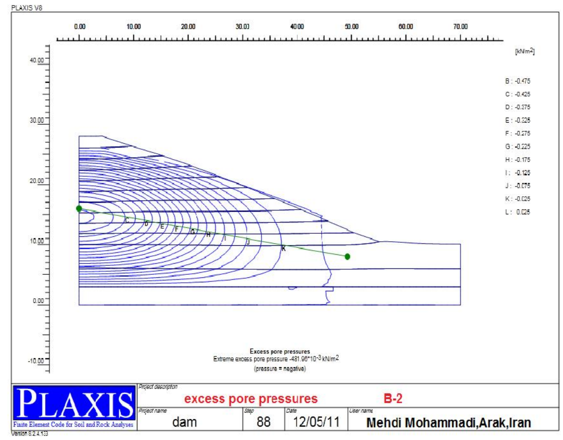

Fig. 14: counter of excess pore pressure after 50 days of consolidation in model B-2

In Fig. 13 and 14, based on excess pore pressure after consolidation the maximum rate for models (B-1) and (B-2) recorded lower than $1\ ^{KN}/_{M^2}$.

Table 5: changes of pace of embankment construction with different slopes in models (A) and (B)

Model (B) Slope 1:2.5 Increase of construction pace ⇐		**Slope 1:5 Model (A)** Increase of construction pace ⇐		
B-2	**B-1**	**A-2**	**A-1**	**Model**
50 days	**240 days**	**50 days**	**240 days**	Consolidation time
5 days	**5 days**	**5 days**	**5 days**	Time per each layer consolidation
m20	**m20**	**m20**	**m20**	Dam height
m2	**m2**	**m2**	**m2**	Layer thickness
10 layers	**10 layers**	**10 layers**	**10 layers**	Number of layers
m8	**m8**	**m8**	**m8**	Width of dam crest
Soft	**Soft**	**Soft**	**Soft**	Footing earth
m2.2	**m1.6**	**m1.4**	**m1.2**	highest settlement
m0.6	**m0.3**	**m 0.1**	**m0.1**	Highest raising in toe
m1.8	**m1.2**	**m0.85**	**m 0.68**	Maximum horizontal displacement (x)

In these tables the effects of increases in embankment paced is evident. Thus, it could be said that accordingly:

1. by an increase in pace of embankment, settlement enhances and through increase of slope the settlement intensify consequently.
2. Embankment pace raises the horizontal displacement enhances and the increase of slope leads to displacement maximization.
3. through pace of embankment, raising in toe goes up and development of slope brings intensification of raising.
4. Increase of pace of embankment reduces stability of slope.

Based on Table 5, increases of dam height as a result of upper layers results to development of toe raising, settlement and horizontal displacement due to the weight of upper layers.

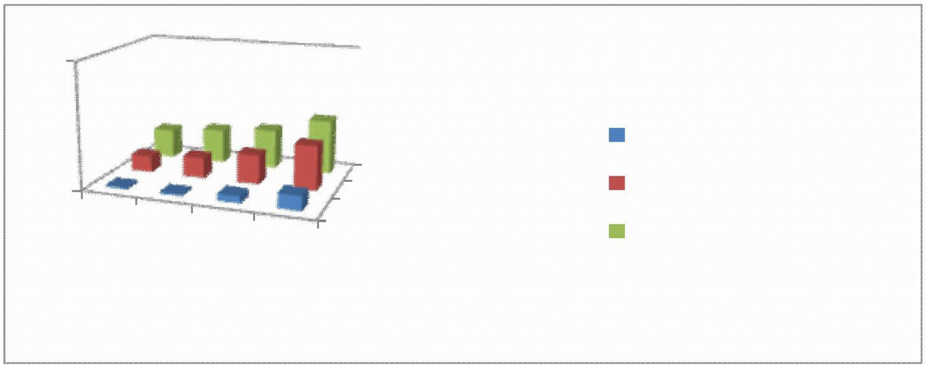

Fig.15: changes caused by pace of embankment construction and slope in models (A) and (B)

The changes created as a result of pace of embankment construction and slope are presented in Fig.15 of models (A) and (B) which are ascending increasing. Based on Fig.15, the increase of settlement, horizontal displacement and toe up lifting in model B-1 could be observable. Also, because of slope and settlement development, the horizontal displacement and toe up lifting as a result of pace of embankment in model A-2 and B-2 are clear.

4. Conclusion

Stability of earth dams on soft earth depends upon different factors in which the pace of dam construction is one of those factors. In earth dams, through development of embankment pace the stability decreases and maximizes as the slope increases. In other words, by reduction of body slope the increase of embankment pace considered effective on being more stable. Therefore, regarding high cost of dam construction, through economic estimation determine the optimum pace and slope of dam construction. Thus, as the results of Table 5 , the changes resulted from increased pace of embankment (reduction of layers consolidation from 240 to 50 days) with two different slopes and the same materials might be obtainable.Table 6 shows the results.

Table 6: changes resulted from increased pace of embankment construction in earth dam

Slop 1:2.5	Slop 1:5	Slop
0.6 m	0.2 m	settlement changes
0.3 m	0	changes of raising in toe
0.6 m	0.18 m	changes of horizontal displacement
20 m	20 m	dam height
8 m	8 m	width of dam crest
Soft	Soft	footing earth

As Table 6 indicates, by increase of dam height due to the weight upper layers the rate of settlement, toe raising, and horizontal displacement are enhanced. So, it could be seen that the rate of up lifting in toe affected by pace of embankment construction increases as slope maximizes. This means, because of embankment construction pace in moderate slopes the toe up lifting is insignificant.

Fig. 16 shows the changes of increasing pace of dam embankment construction which are higher in steep slope rather moderate ones. This study proved that the rate of embankment construction plays a significant role in its stability.

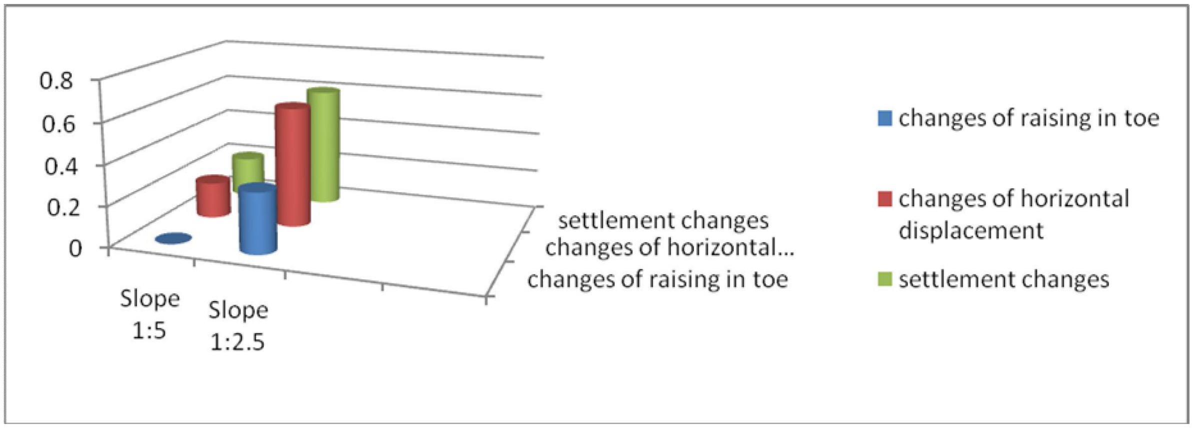

Fig. 16: changes resulted from increased pace of dam embankment

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