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Evaluation of the Effect of Modulus of Elasticity in Clay Core on the Arching in the Crest of Earth Dams

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ABSTRACT

The results of analysis of effect the modulus of elasticity *(E)* on the deposition changes are considerable. In practice, these factors can have an effect on displacement value and stress in the earth dam. Hence, the effect of this parameter on the unequal settlement and stress created in in the crest of dam is assessed using the finite element method (FEM). The results showed that by increasing the value of modulus of elasticity *(E)* of the clay core and decreasing the difference of modulus of elasticity in the clay core and modulus of elasticity of the crust, the vertical displacement value in the crest of dam is decreased notably. The results showed that by decreasing the difference between the modulus of elasticity (E) in clay core and crust, reaches to zero, the value of unequal settlement at the crest of dam decrease to less than 1 mm. When the modulus of elasticity (E) in clay core is less than 50% of the modulus of elasticity (E) crust, the arching increases.

1. Introduction

Earth dams are structures that built of natural materials such as rock fragments, gravel or combination of clay and silt. Despite concrete dams, earth dams have flexible nature and may be

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built on any material. It is enough that accommodate the section of dams to the existing foundation form and use natural material and combination of gravel and clay and silt and even big rock segments. For building of earth dams, a sort of thin clay core blocks water. Clay has a nature material that when it moistens, it becomes a good waterproof. Except for clay core, the crust of dams is built out of rock and water-insoluble soil [1].

To choose materials for the core earth dams, materials should be chosen that have a little permeability coefficient after the water retention of the dam. Also, crust materials have a good permeability to downfall pore pressure. It is notable that because of fall and rise creep of the materials and also settlement of the dam bed, the crest may get curving and dropping. In cases that this curving is more significant, they tried to fulfill pollen or reverse curving crest so that after fall and rise of the material and settlement of the dam bed, the crest becomes flat and horizontal [2].

There are different studies about the interaction of two adjacent environments with the same soil under static and harmonic loads. Because soil is a semi-infinite continuum and because the soil is part of this study and approach for modeling the environment of soil and action of soil (the relationship between power- displacements of soil) is very effective on the result of analysis [3]. In 1885, Hertz investigated the interaction of elasticity bodies under vertical loads for the first time. He obtained the development of tension in the contact area using potential theory. For example, Obtained results by Hertz about two frictionless spheres that are in contact and under a set of forces that their effect lines are in one line and cross from the center of the sphere [4].

The history of the theoretical and numerical studies of settlement in the crest of dam extends years before. Nejad et al. [5] studied the seismic deformation analysis of a rock fill dam with a bituminous concrete core. They have reported the effects of seismic deformation analyses of Shur River Dam. Nayebzadeh and Mohammadi [6] studied the effect of impervious clay core shape on the stability of earth dams. Talebi et al. [7] evaluated the effect of geomechanical and geometrical factors on soil arching in zoned earth dams. Moradi et al. [8] studied an approximate equalization for the evaluation of arching due to the shape and hardness of the valley in earth dams.

Ghafari et al. [9] use of the finite element analysis studied the deformation and arching inside the core of earth dams during construction. Rashidi and Haeri [10] evaluated the behaviors of earth and rockfill dams during construction and initial impounding using instrumentation data and numerical modeling. Yu et al. [11] evaluated the large-deformation finite element analysis of the interaction between concrete cut-off walls and high-plasticity clay in an earth core dam. Feng et al. [12] evaluated the evaluation of the arching effect in geosynthetic-reinforced structures. Rashidi et al. [13] studied the numerical analysis and monitoring of an earth dam during construction and first impounding. Esmaeilzadeh et al. [14] evaluated the arching parametric study on earth dams by numerical modeling.

2. Numerical methods

This study concerns analysis of the evaluation of the effect of modulus of elasticity in clay core on the arching in the earth dam. In this section, the numerical methods can be defined as follows:

The behavior of both the shell and clay core of the earth dam is described using Mohr-Coulomb criterion.

Finite element method (FEM) by means of PLAXIS software was used for analyzing. Note that all analyses were performed under the plane strain condition.

Fig. 1. shows the dimensions of numerical model. An inhomogeneous embankment with an upright clay core was considered, which is 10 m high, 5 m long and 5 m deep. The slope of crusts is 1 to 4 and the slope of the core in upstream and downstream is 2 to 3. The width of embankment floor is 85 m, each crust is 26 m and the width of core floor was considered 33 m. Due to permeability of lower part of the foundation, the clay core did not continue in foundation.

The bottom boundary was fixed in both directions, the laterals boundaries were fixed in horizontal direction and soil consolidation and flow boundaries are closed.

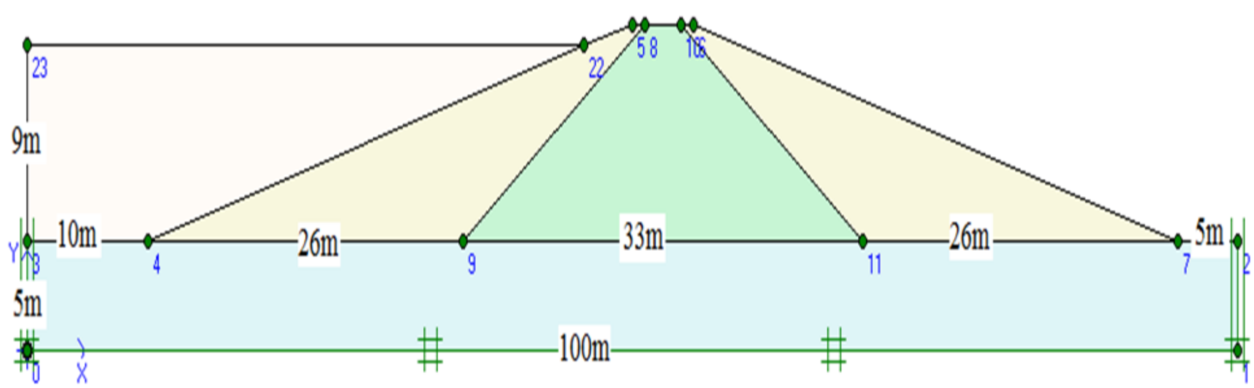

Fig. 1. Geometry of the numerical model.

3. Materials properties

An earth dam has homogeneous and isotropic properties with vertical clay core. Table 1 showed the characteristics of different parts of an earth dam. The simple Mohr-coulomb model is used for the action of materials. Clay core, Up-stream crust, and foundations are in untrained mode and Down-stream crust is in drained mode. Modulus of elasticity (E) is considered a variable.

4. Loading modes

To meshing elements of earth dam system, elements with tiny sizes are used. This study is conducted in three different groundwater level modes and also is conducted for each harmonic analysis mode in two parts of applying the effect of interaction of structure and water and lack of applying the effect of interaction. In the static mode, the interaction of water and soil is not considered because of using high-reliability modulus in design. The first loading mode is considered a base mode in the analysis.

Table1
Characteristics of the earth dam.

Characteristics	Up-stream crust	Down-stream crust	Dam core	Foundation
Cohesion (*KN/m²*)	1	1	30	5
Angle of internal friction (degree)	35	35	5	15
Dry unit weight of soil *(KN/m³)*	18	18	16.5	18
Saturated unit weight of soil *(KN/m³)*	21	21	18	19.5
The coefficient of permeability, for horizontal flow *(m/day)*	1	1	0.001	0.01
The coefficient of permeability, for vertical flow *(m/day)*	1	1	0.001	0.01
Elasticity coefficient *(KN /m²)*	2×10^4	2×10^4	variable	10×10^3
Poisons ratio	0.3	0.3	0.35	0.3

- The first mode is when water level is on the earth dam bed. It is a base mode.

- The second mode is when water level is in the height of *0.9h* from the earth dam bed and phreatic line doesn't enter the down-stream crust.

- The third mode is when water level is in the height of 0.9h from the earth dam bed and phreatic line enters the down-stream crust, under the condition of investigating static and harmonic.

5. Results and discussion

One of the dangers affecting the integrity of the clay core of dams and consequently the dam's stability is arching. Due to the various elasticity *(E)* and consequently the different settlement of the core and crust material of an earth dam, a load transfer from the core to the crust occurs during and after dam utilization. This can cause a total stress decline inside the core that can lead to horizontal cracking through arching action.

To harmonic analysis in earth's dam, Calculations of harmonic analysis were done in 250 steps and 1 sub-step (standard mode). The time needed to apply harmonic load is 20 seconds and 10 Hz frequency ~~is~~ applied the sample. In harmonic analyze, the primary displacement of the model due to static load, and settlement is considered zero, and the effect of primary displacement is not considered in harmonic analysis. The results of the analysis of elasticity effect on changes of settlement and stress are presented in table 2. In this study seven models with fixed properties are investigated that in any mode only modulus of elasticity of core is considered as a variable. The modulus of elasticity of the crust is 20×10^3. Different modulus of elasticity is used for the clay core in the analysis which are:

2×10^3, 4×10^3, 6×10^3, 8×10^3, 10×10^3, 15×10^3, 20×10^3

Table 2
The results of the analysis of elasticity effect on changes of settlement and stress.

Elasticity coefficient of clay core *E (KN/m²)*	Vertical displacement in crest edge *(mm)*	Maximum vertical displacement of the crest center *(mm)*	The difference of Elasticity coefficient logarithm in clay core with crust *(KN/m²)*	Vertical displacement difference of the center of crest with the crest edge *(mm)*	Maximum vertical stress *(KN/m²)*
2000	211.1	288.23	18000	77.13	249.46
4000	193.45	222.85	16000	23.4	247.86
6000	142.33	161.26	14000	18.93	247.59
8000	125.44	138.21	12000	12.77	246.86
10000	118.17	124.43	10000	7.26	245.89
15000	79	82.81	5000	3.81	245.45
20000	62.42	62.92	0	0.50	245.48

The results obtained from the analysis of earth dam with the different modulus of elasticity shown that by increasing modulus of elasticity of the core, the amount of vertical displacement decreases so that by increasing modulus of elasticity from 2×10^3 to 4×10^3 (100%), maximum vertical displacement in the center of crest decreases to 22.5%. Decrease of the amount of settlement of the crest versus modulus of elasticity is much at first and is in the medium slope of 2.2%, and after 8×10^3 modulus of elasticity (0.4 moduli of elasticity of crust) diagram slope decreases and becomes 1.3%.

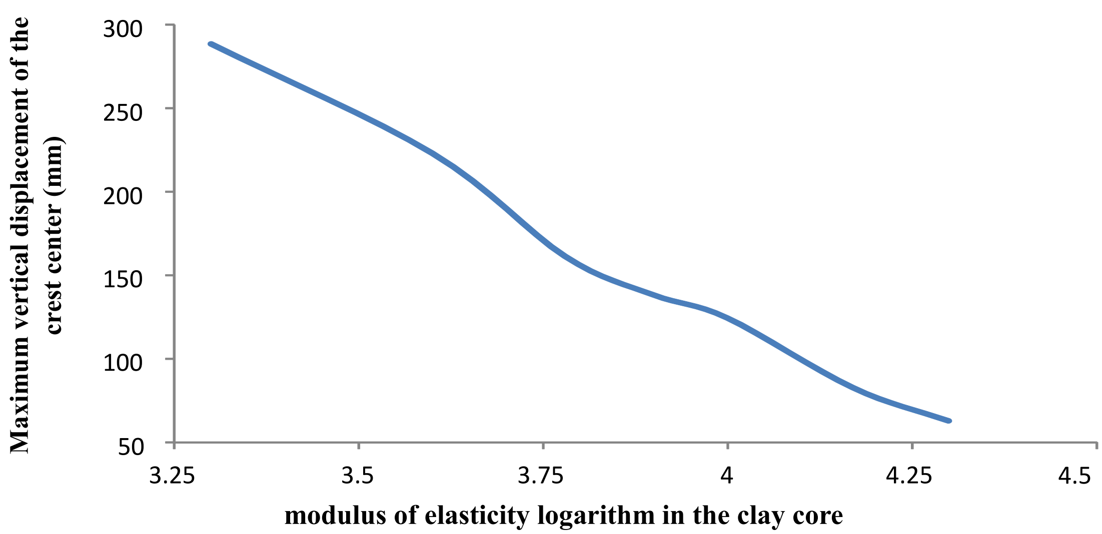

Fig. 2. Changes diagram of maximum vertical displacement of crest.

Fig. 2. showed changes diagram of maximum vertical displacement of crest versus modulus of elasticity logarithm of the clay core. The modulus of elasticity difference in different areas of the earth dam body impacts significantly on conditions of displacements so that by increasing modulus of elasticity of the core, the amount of vertical displacement in the dam body becomes steady and the amount of curving decreases. as shown in the diagram of Fig. 2, by increasing the modulus of elasticity difference of clay core and crust, the amount of vertical displacement difference of the center of crest with the crest edge increases so that by 20% increase of the modulus of elasticity difference, two adjacent areas of the vertical displacement difference of the center of crest with the crest edge increases 50% at first and after then increases 62%.

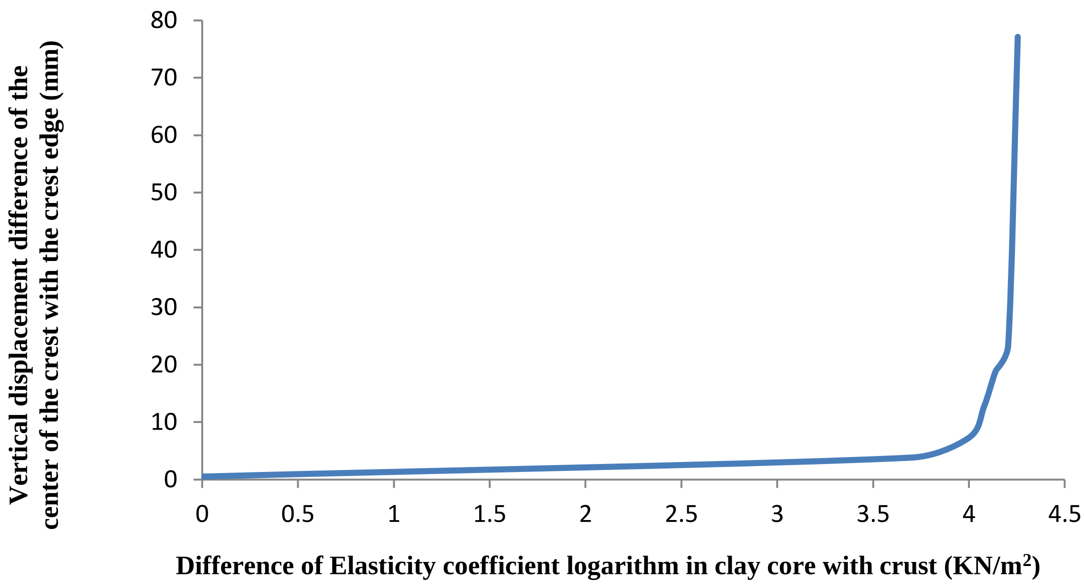

Fig.3. Changes diagram of the vertical displacement difference of the center and crests edge.

In the diagram of Fig. 3. the vertical displacement difference of the center of the crest with the crest edge versus the modulus of elasticity difference logarithm of the clay core and crust is showed. According to this figure, when the amount of modulus of elasticity difference of the clay core and crust becomes zero from 18×10^3, the amount of vertical displacement difference of the center of crest with the crest edge becomes less than 1 mm.

When the value of modulus of elasticity (E) in clay core is more than 50% of the modulus of elasticity (E) crust, the effect value of the modulus of elasticity (E) on arching is negligible.

When modulus of elasticity (E) in clay core is less than 50% of modulus of elasticity (E) crust, the arching increases. Also, when the modulus of elasticity (E) in clay core is less than 20% of the modulus of elasticity (E) crust, the amount of arching increases sharply.

Fig. 4. showed the vertical displacement variations of the dam crest versus the logarithm of modulation of the clay core modulus of elasticity (E). Increasing the modulus of elasticity (E) of the earth dam core reduces the vertical displacement at the edge of dam crest and crust. The decrease in the subsidence in the dam crust, in this case, is due to the decrease in the dam

nucleation, which is caused by an increase in the core strength due to the increase in the modulus of elasticity (E). The results shown that if the hardness of a part of the structure increases, the strength of the earth dam increases to converge the hardness of the whole structure.

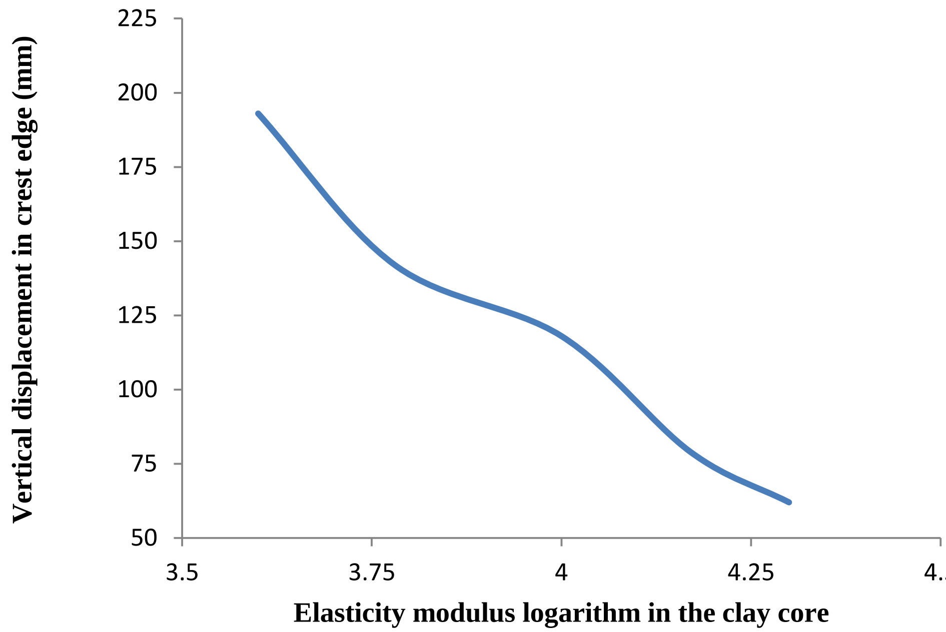

Fig.4. Changes diagram of vertical displacement in crest edge (mm).

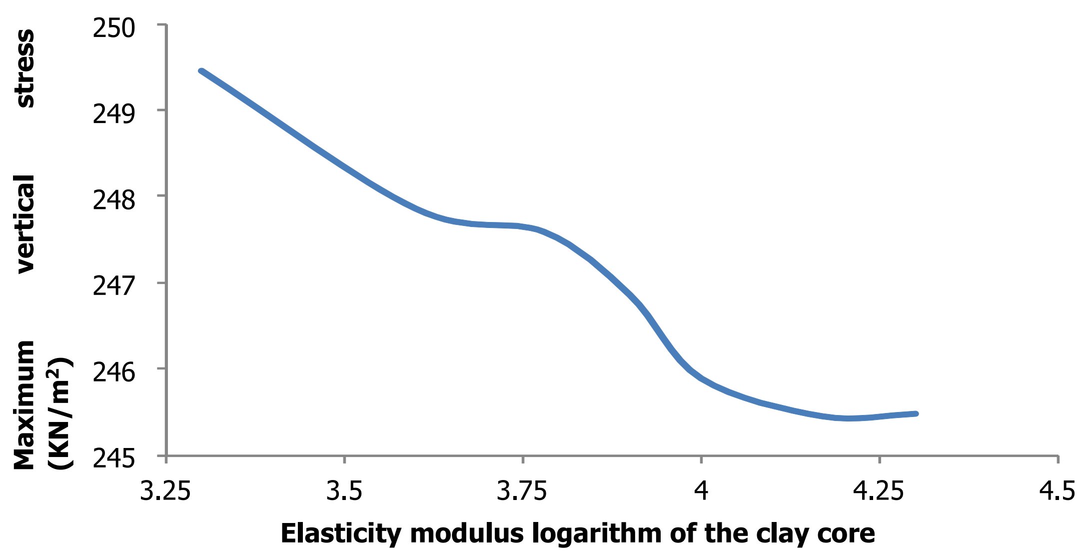

Fig. 5. Changes diagram of maximum vertical stress (KN/m2).

Fig. 5. showed the maximum vertical stress variation in the dam body versus the logarithm of clay core modulus of elasticity (E). Increasing the modulus of elasticity (E) of the earth dam core causes a very slight decrease in the maximum vertical stress in the dam body.

6. Conclusions

The results obtained from this analysis showed an earth dam with the different modulus of elasticity that by increasing of modulus of elasticity of the core, the amount of vertical displacement decreases so that by increasing modulus of elasticity from 2×10^3 to 4×10^3 to the 100%, maximum vertical displacement in the center of crest decreases to 22.5%. Decrease of the amount of deposition of the crest versus modulus of elasticity is much at first and is in the medium slope of 2.2%, and after 8×10^3 modulus of elasticity (0.4 modulus of elasticity of crust) diagram slope decreases and becomes 1.3%.

- Changes of the vertical displacement differences of the center of crest with the crest edge versus the difference logarithm of modulus of elasticity the clay core and crust, by increasing the modulus of elasticity difference of the clay core and crust, the amount of vertical displacement difference of the center of crest with the crest edge increases so that by 20% increase of the modulus of elasticity difference, two adjacent areas of the vertical displacement difference of the center of crest with the crest edge increases 50% at first and then increases 62%.
- According to the results, when the difference between the elasticity coefficient in clay core and shell reaches to zero, the value of the vertical displacement difference between the center of dam crest and the edge reaches less than 1 mm.
- By increasing the elasticity of the clay core, various methods such as the use of geosynthetics, composites, etc. can reduce the amount of arching in earth dams.
- The effect of modulus of elasticity on arching in soil dams is considerable but should be considered simultaneously with other factors such as Poisson's coefficient, clay core resistance parameters, reservoir and dam geometry.

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