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Effect of Embankment Soil Layers on Stress-Strain Characteristics

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Abstract: Dam embankments are complex geotechnical structures. In design of the earth dams, the finite element method (FEM) is very often used. The FEM is used in analysis of expected displacements, strains, and stresses of the structure caused by changeable loading or boundary conditions. Deformation of an embankment dam starts occurring during the construction of the dam. These deformations are caused by the increase of effective stresses during the construction of the consecutive layers of earth material and also by the effects of creep of material. In this study, Alavian earth dam was selected for stress-strain analysis using Geo-Studio software. The settlements from the single layer embankment simulations were compared with the settlements calculated for 3, 7, 10 and 15 soil layers considered in construction processes. Results showed that maximum displacement in single layer dam has happened in the crest of the dam. Increase in embankment layers, resulted in the maximum displacement creation in the middle of the downstream shell. The simulation layers for the construction have little effect on the stresses in the dam; however, that may cause a significant effect on the deformations of the dam.

Key words: Alavian embankment · Deformation · Simulation · Soil layer · Settlement

INTRODUCTION

Dams are very important social and economical issues of water reservoirs. Due to changes of geology and other criteria of dams; these structures may also changes. For the specified reasons, dams should certainly be designed and built with high assurance for a long duration of time [1].

An earth dam is a dam built with highly compacted soils. It is classified as a type of embankment dam, being built in the shape of an embankment or wedge which blocks a waterway. In addition to soil, other materials such as rock and clay are also used in earth dams. Earth dams have been built by various human societies for centuries as they are most cost effective and are built from materials available in the nearby locations [2]. Embankment dams are complex geotechnical structures [3].

Finite element method is a powerful tool to analyze and solve problems in constructions of the embankment dam as it can calculate the internal deformation of the core and shell so that the stress distribution and load transfer within a dam section can be obtained. Many researchers have used this method to investigate the deformations and stresses in embankment dams [4].

At the end of the construction of a dam, the considerable movements of the crest and the body of the dam can be developed during the first completion of the reservoir. Later, the rate of deformations gradually decreases with respect to time, with the exception of variations associated to the periodic variations of the level of the reservoir and in seismic zones due to the earthquakes.

Intensity, rate and direction of movements, in a specific point of the body of the dam or its crest, can vary during the various phases of the construction and the operation of the reservoir [5].

Based on reported literature with different testing results, Boughton [6] developed specific equations for the nonlinear elastic modulus and Possion's ratio and he has computed the deformations of a dumped rock fill dam. Duncan and Chang [7] proposed a hyperbolic constitutive model for the nonlinear stress-strain relationship of soil, which has often been used for stress and deformation

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analysis in embankment dams. Martin [8] used an isoparametric element with a quadratic displacement function and the substructure method to perform a three-dimensional finite element analysis for an 80 *m* high rock fill dam. Alonso *et al*. [9] proposed a constitutive model for the partially saturated soil that permits stress-strain analysis of earth and rock fill dams [10, 11].

Rice and Duncan [12] presented a procedure for analyzing postconstruction deformation of seepage barriers due to changes in the pore pressure regime after seepage barrier construction. The procedure uses the changes in pore pressures calculated by finite-element seepage analyses to calculate changes in buoyancy and seepage forces that occur as a result of seepage barrier construction. When the buoyancy and seepage forces are applied to a finite-element soil-structure interaction model, the result is an effective-stress analysis that rigorously models seepage effects. The results of the analyses indicate that deformation due to pore pressure regime changes is a likely mechanism causing cracking in rigid seepage barriers.

The objective of Sengupta's research [13] was to find the permanent deformations of Tehri dam due to an earthquake of magnitude 8.5, the occurrence of which has a high probability in the region, and for an earthquake of magnitude 7.0, for which the dam has been currently designed. Instead of finite element analysis, five different empirical methods, Makdisi and Seed's method, Newmark's double integration method, Jansen's method, Swaisgood's method and Bureau's method have been utilized and their results compared to get a range of values within which the permanent deformation of the dam is estimated to lie.

Perlea *et al*. [14] investigated on Success Dam and the Auxiliary Dam of the Isabella Lake, both in California. These dams have recently been evaluated for seismic loading and seismic risk. The dams are founded on liquefiable alluvium deposits and in one case the site has a seismically active fault that transects the dam. Seismic deformation analyses for the risk assessment were performed using the computer program FLAC and the liquefaction model UBCSAND. Correlation relationships were determined between the intensity of shaking (defined by the peak ground acceleration) and embankment deformations, in particular the crest settlement and the horizontal displacement of the slopes. The results were presented in a format adequate for easy implementation into the risk evaluation model.

In this study, Alavian earth dam was selected for stress-strain analysis using Sigma/w, a part of Geo-Studio (v. 2007) software. A two dimensional plane strain finite element method was used to investigate the stresses and deformations of Alavian earth dam and the method was proposed to solve the problem of nonlinear material properties.

MATERIAL AND METHODS

Location of Alavian Earth Dam: Alavian dam is an earth dam with clay core, made on Sufi-Chay River 3.5 km of northern west of Maragheh city in eastern Azerbaijan, Iran. The main aim of Alavian dam construction is to collect surface river flows and controlling Sufi-Chay River for the purpose of supplying drinking water of Maragheh city, development of agriculture lands and hydroelectric uses. The height of the dam from the bed rock is 76 meters, the dam has 935 meters length, the width of crest is 10 meters, total volume of dam's soil material is 4.8 million cubic meters, the crest elevation is 1572 meters from mean free surface of sea, the reservoir volume in normal level is 60 million cubic meters and dead volume is 3 million cubic meters [15].

Figure 1 shows location of Alavian earth dam in Iran and in eastern Azerbaijan province.

Numerical Simulation: Sigma/w software (v.2007) was used for simulation of Alaviyan dam (Fig. 2). Upstream boundary condition was selected as total head equal to 72 meters from the base/bed rock and downstream as total head equal to 14 meters. Quads and triangles elements were used for simulation. Total number of meshes was about 3500.

In this work, five models with different number of layers are defined for the specified dam. The numbers of layers were 1, 3, 7, 10 and 15. Fig. 3 shows mesh pattern for the dam with 3 layers.

The analysis was performed using finite element method with the Linear Elastic model of the earth dam material. The dam was divided into different construction layers giving the total height of 76*m* (Fig. 3). The analyzed dam rested on the non-deformable bedrock. The modeled dam was divided into four zones: core (zone 1), upstream and downstream filters (zone 2), upstream and downstream rock fill shells (zone 3) and dam foundation (zone 4). The load/deformation analysis type is used for all models.

Fig. 1: Location of Alavian earth dam in Iran map (above) and in eastern Azerbaijan province in Iran (down)

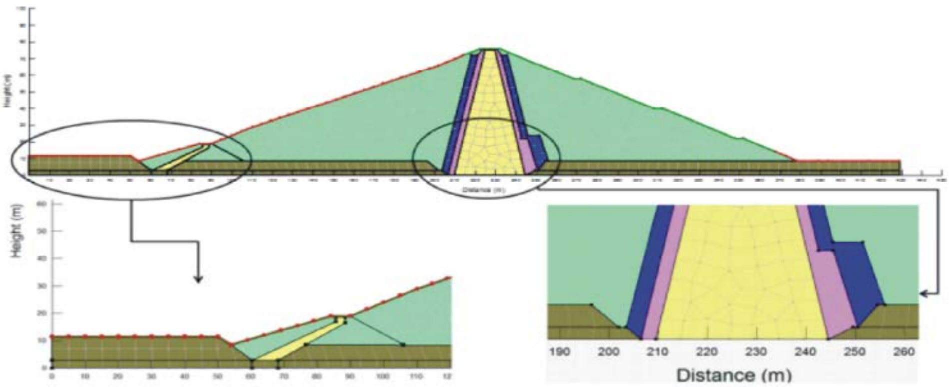

Fig. 2: Cross section of Alavian dam with details of mesh generation

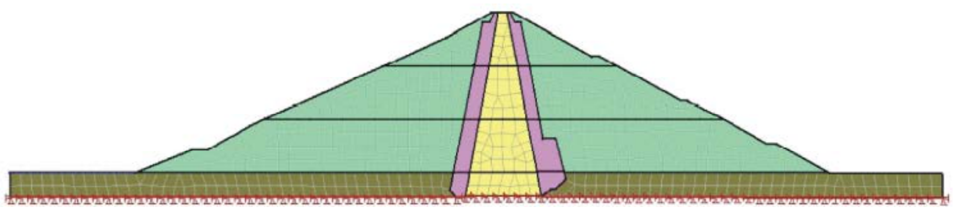

Fig. 3: Mesh generations of dam with 3 construction layers in numerical analysis

RESULTS AND DISCUSSION

Embankment Deformations: Embankment deformations under static loading occur as a result of volumetric changes, lateral spreading, or shear displacements within the embankment and foundation materials [16].

Figure 4 shows counters of displacement in *xy*-plots in dam with various layers. Based on Fig. 4 (dam with one construction layer), maximum displacement occurs in the crest of dam and in the middle of the upstream and downstream of dam shell. The settlement pattern was symmetric and showed almost equal outward movements to the left and right directions. The largest deformation of the levee occurred on the crest, and the smallest deformation occurred at the deeper part of foundation, as shown in Fig. 4.

Counters of displacement in Fig. 4 (dam with 7 layers) have significant changes respect to dam with 1 layer.

The settlement pattern in dam with 7 layers was not symmetric and much more complex than that of the embankment with single layer (Fig. 4). The maximum settlement appeared at the downstream side of the embankment. The settlement differences in the crest were significant for 1 and 7 layers of embankment. This complex settlement pattern was caused by the staged construction of the two embankments and by the corresponding spatial differences of layered soil in dam construction.

In Fig. 4, the settlement of the foundation soil below the embankment was much larger than that of the foundation soil away from embankment; thus, the foundation soil below the embankment can be inferred to be substantially consolidated rather than the part away from the embankment.

Figure 5 shows X-displacement and Y-displacement curves for dam with different number of layers. All displacements values are from the dam axes (a vertical line from middle of dam core). From Fig. 5, it can be see that maximum settlement occurs in the dam with 10 layers and is about 9*cm* in *x* direction in 18*m* above dam foundation.

In other hand, the Maximum Y-displacement is 1.3*m* above 50*m* of the dam foundation (Fig. 5).

Figure 6 presents *xy* contours displacements in the dam with different number of layers (1, 7 and 15). In these simulated models, white portion shows dam before displacement and grey color zone represent dam after settlement. Based on Fig. 6, settlement near the dam crest is more than the other models.

The simulation layers for construction have a significant effect on the deformations of the dam. Both settlements and displacements of the dam nonlinearly decrease with the increasing quantity of simulation layers. The change in the deformation with the variation in number of layers is small if the quantity of simulation layers is more than 10.

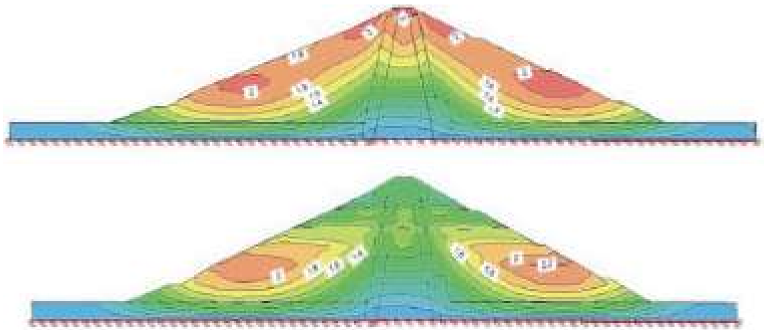

Fig. 4: Counters of *xy* displacement in dam with 1 layer (left) and 7 layers (right)

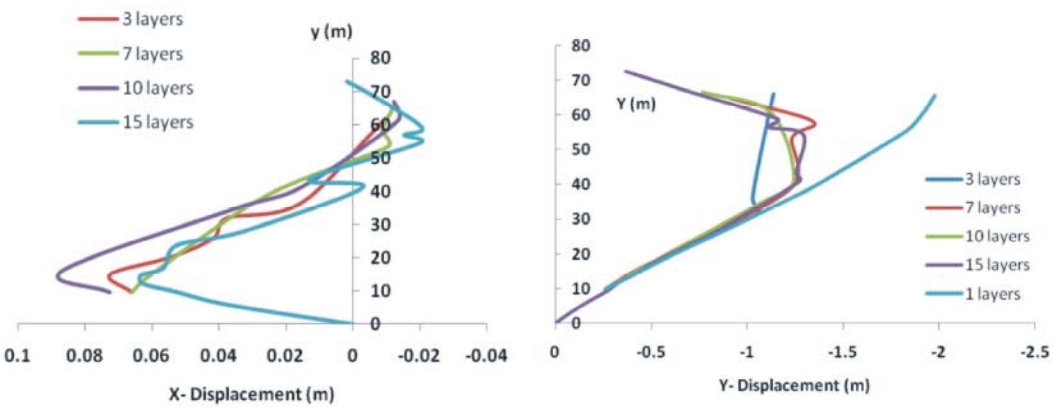

Fig. 5: X- Displacements (above) and Y- Displacement (down) versus height of dam with different layers after dam construction

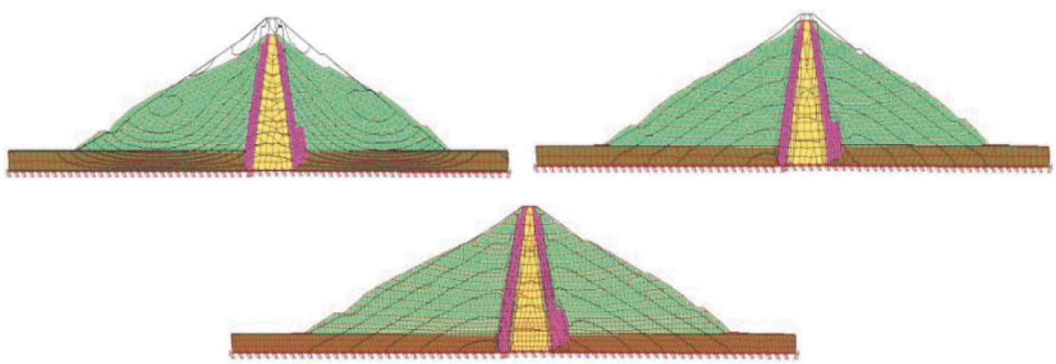

Fig. 6: Deformation of dam with 1 layer (above left), 7 layers (above right) and 15 layers (down) after dam construction

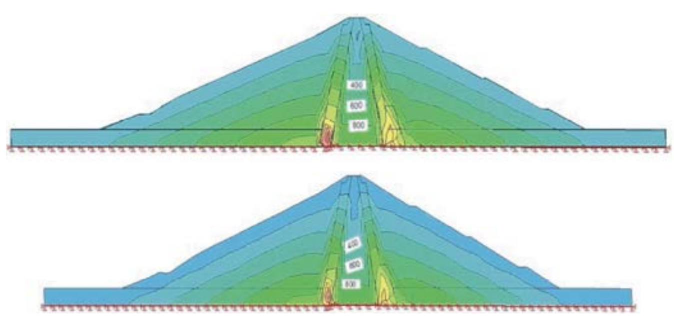

Fig. 7: Counters of total stress in dam with 1 layer (left) and 10 layers (right)

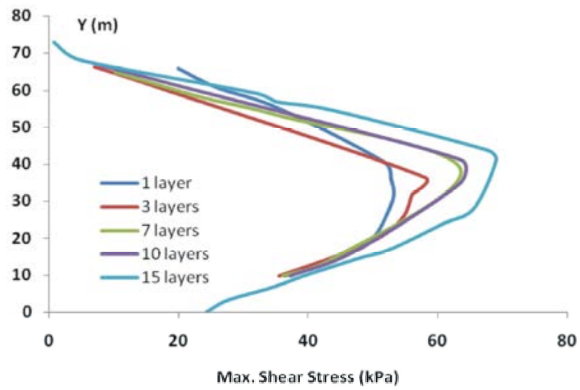

Fig. 8: Variation of shear stress versus depth of dam with different layers

Figure 7 shows counters of total stress in dam with 1 and 10 layers respectively. In these cases, total stress increases from crest to the bottom of the dam. At the same elevation, the stress in the core is less than that in the other parts of the dam. Results confirmed with the effect of observed arching.

Comparison among Figs. 4 and 7 demonstrates that simulation layers for construction have little effect on the stresses in the dam but have a significant effect on the deformations of the dam.

Figure 8 shows values of shear stress versus depth of dam for different layers. Vertical cross section is considered in middle/axis of the dam. In the middle of embankment (Y=40*m*), maximum shear stress is happen and it increases slightly with increase in number of layers. This demonstrates significant of number of layers in predicting of shear stress in embankment. Must of researches suggest that consideration of 10 layers for embankment would be adequate for numerical simulation.

A good understanding of the deformations, which occur in embankment dams, will allow minimizing the effects such as: transverse cracking, longitudinal fissuring, arching effect and stress concentration, hydraulic fracturing, development of plastic zones and damages in the instrumentation [17].

CONCLUSION

In this study, the deformation pattern of the Alavian embankment and foundation was analyzed using Geo-Studio software. The settlements from the single layer embankment simulation were compared with the settlements calculated for 3, 7, 10 and 15 layered embankments for considering construction processes. Based on analysis of the numerical simulation, the following conclusions are drawn:

- Embankment settlement showed different patterns based on variation in the number of layers conditions. Maximum displacement in single layer dam has happened in the crest of dam. Increase in embankment layers, results in changes of the maximum displacement creation in the middle of the downstream of the dam.
- The change in the deformation with the variation in number of layers is small if the quantity of simulation layers is more than 10.
- At the same elevation, the stress in the core is less than that in the other parts of the dam. Results confirmed the effect of observed arching.

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Persian Abstract

چکیده

سدهای خاکی جزو سازه های ژئوتکنیکی پیچیده هستند. در طراحی سدهای خاکی اغلب از روش عناصر محدود استفاده می گردد. برای تجزیه و تحلیل مقادیر جابجایی ها، تنش و کرنش در سازه بر اثر تغییر بارگذاری و یا شرایط مرزی از روش عناصر محدود استفاده می شود. تغییر شکل در قسمت های مختلف یک سد خاکی از زمان شروع ساخت آن آغاز می گردد. این تغییر شکل ها بر اثر افزایش تنش موثر هنگام ساخت لایه به لایه سد خاکی و نیز به علت خزش مصالح اتفاق می افتند. در این مطالعه سد خاکی علویان جهت بررسی تنش و کرنش در بدنه و پی آن توسط نرم افزار Geo-Studio انتخاب گردیده است. نشست خاک در این سد با یک لایه به صورت عددی شبیه سازی شده و با مقادیر نظیر با تعداد لایه های متفاوت ۳، ۷، ۱۰ و ۱۵ مورد مقایسه قرار گرفته است. نتایج نشان می دهند که حداکثر جابجایی در سد با یک لایه در نزدیکی تاج سد اتفاق می افتد. با افزایش تعداد لایه های ساخت - که بیشتر با شرایط واقعی همخوانی دارد- حداکثر جابجایی ها در مرکز پوسته پایین دست مشاهده گردید. شبیه سازی تعداد لایه های مختلف نشان داد که مقدار تنش کل نسبت به تعداد لایه ها حساس نیست ولی مقادیر تغییر شکل ها به تعداد لایه ها حساس بود که باید در طراحی اینگونه سدها مورد توجه قرار گیرد.