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Research Article

EFFECT OF HEIGHT VARIATION ON THE STRESS-STRAIN ANALYSIS OF THE HETEROGENEOUS EMBANKMENT DAMS

***Mohsen Yazdanian[1], Sadegh Ghasemi[1] and Hamid Reza Afshoon[2]**
[1]*Young Researchers and Elite Club, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran*
[2]*Department of Agriculture, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran*
**Author for Correspondence*

ABSTRACT
In recent years, it has become clear that the deformation in the dam body and foundation is very important and should be designed to prevent the cracks in the dam and to be controlled if possible. Since in the heterogeneous dam, the difference in motion among different materials may be occurring during the dam catchment, so stress - strain analysis at catchment phase is of crucial importance. Hence in the present study, the effect of height on the stress - strain analysis of two heterogeneous embankment dams with similar characteristics but with different heights have been investigated. To study the effect of height, two dams with a height of 62 and 133 meters long and 6 meters in crest width were modeled in Geostudio. Both embankment dams are composed by 11 different areas with different characteristics. For the stress-strain analysis of dam, SIGMA/W in Geostudio was used and the results showed that the stresses and displacements created in shorter dams is less than the dam with higher heights.

Keywords: *Embankment Dam, Heterogeneous, Height, Stress, Strain, SIGMA/W*

INTRODUCTION
The safety of large built structures, the environmental protection and the development of associated mitigating measures in the case of natural disasters, require a good understanding of the causes and the mechanism of the structural deformation process (Gikas and Sakellariou, 2008).
A dam is a structure built for upon a stream, river, or waterway for the purpose of restrict and managing the flow of water. Dams are constructed for particular duty such as water supply, irrigation, flood managing and also to produce hydroelectric power (Chaoyang and Zhenzhen, 2011; Novak *et al.*, 2001). Because of changes of geology and other parameters of embankment dams; these dams may also changes. For the specified reasons, dams should certainly be designed and built with high assurance for a long duration of time (Beheshti *et al.*, 2013). There are two types of modern dam namely embankment dam and concrete dam. Many researchers investigated on the stress- strain of embankment dam. Khoei *et al.*, (2004) used finite element method for considering the moist, non-moist and plastic characteristics of soil. This method is performed on three dams by applying the suggested model.
(Szostak *et al.*, 2005) considered geometric parameters in a stress- deformation of embankment dam at the procedure of changing the height of water. The applying this method, provided a realistic model of strain and described the behavior of the dam under the research. Chakraborty and Choudhury (2007), applied software program for investigates probability of happening of large strain, it is resulted that with the rise of the height of an embankment dam, large strain will be create. Bulatov and Gatanov (2012), suggests a procedure for predicting the performance of embankment dam and also the value of reliability in deformations, which resulted from external effects and evaluating the factor for protecting of technology measures.
Applying Finite element method (FEM) is a suitable method for analyzing and solving problems in designing of the embankment dam. In fact it can evaluate the internal strain of the core and shell so that the stress intensity and load transfer in a dam body can be resulted (Chen *et al.*, 2014).
Considering the items mentioned above and knowing that dams are structures which disruption and deterioration can cause irreparable financial and physical damages, stress –strain analysis of embankment dams is of utmost importance. Therefore in this study, stress –strain analysis was done on two embankment dams with different heights and using finite element software (Geostudio, 2007).

MATERIALS AND METHODS

In this paper, Geostudio 2007 is used to model two embankment dams. To study the effects of height, two dams with a height of 62 and 133 meters and 6 meters crest width were modeled in Geostudio. For dam stress - strain analysis, SIGMA/W (2007) was used. This part of the application is related to the analysis of the stress - strain (Load/Deformation), stress and consolidation that can be used to obtain the total and inter granular stresses and the pore water pressure and through it; the resulting deformation in the soil can be obtained. In modeling, both embankment dams are modeled with the identical materials. Both embankment dams are composed of 11 different areas with different characteristics. One of the best methods to calculate the amount of displacement in the body and foundation of embankment and rock fill dams is the finite element method. In this method, the studied area is divided into components that are connected by joints. In this method, the analysis of the dam materials can be assumed as elastic or with non-linear behavior based on existing rules or the material behavior can be considered as hyperbolic. One of the features of Sigma/W is detailed meshing. In introducing the materials, their behavior in dam body is considered as nonlinear elastic - hyperbolic. The behavior of dam foundation material is also considered as linear elastic. Also, since the rock foundation is connected to other stones from the bottom and surrounding and it is in fact rigid, in introducing the supporting condition, the foundation displacement, in horizontal and vertical directions, is assumed to be built-in support. In Table 1, E stands for elasticity modulus and Rf is the modulus of rupture. This factor is always less than one, and usually between 0.5 and 0.9.

Table 1: Material Characteristic

Poisson's Ratio υ	$c\ (\frac{t}{m^2})$	ϕ	R_f	**E (Kpa)**	$\gamma(\frac{t}{m^3})$	**Material**	
0.334	10	10	0.93	3000	2	Zone1	Clay core
0.35	0	43	0.85	4000	2.1	Zone 2	Downstream
0.35	0	41	0.85	4000	2.1	Zone3	crest
0.35	0	39	0.85	4000	2.1	Zone4	
0.35	0	38	0.85	4000	2.1	Zone5	
0.35	0	37	0.85	4000	2.1	Zone6	
0.35	0	41	0.82	4000	2.1	Zone7	Upstream
0.35	0	39	0.82	4000	2.1	Zone8	crest
0.35	0	37	0.82	4000	2.1	Zone9	
0.35	0	36	0.82	4000	2.1	Zone10	
0.49	-	-	-	500000	2.6	Zone 11	foundation

The behavior of material is assumed linear elastic and Nonlinear Elastic (Hyperbolic). The simplest SIGMA/W soil model is the linear elastic model for which stresses are directly proportional to the strains. The proportionality constants are Young's Modulus, E, and Poisson's Ratio, υ. The stresses and strain are stated by the equation (Stress-Deformation Modeling with SLOPE/W 2007 Version, 2008):

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \sigma_{xy} \end{Bmatrix} = \frac{E}{(1+\upsilon)(1-\upsilon)} \begin{bmatrix} 1-\upsilon & \upsilon & \upsilon & 0 \\ \upsilon & 1-\upsilon & \upsilon & 0 \\ \upsilon & \upsilon & 1-\upsilon & 0 \\ 0 & 0 & 0 & \frac{1-2\upsilon}{2} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \varepsilon_{xy} \end{Bmatrix}$$

For a two-dimensional plane strain problem, ε_z is zero. It is significant that when υ approaches 0.5, the term $\frac{1-2\upsilon}{2}$ approaches zero and the term $1-\upsilon$ approaches υ. This means that the stresses and strains are stated by a constant, which is representative of pure volumetric strain. Furthermore, the term

$\frac{E}{(1+\upsilon)(1-\upsilon)}$ tends towards infinity as $1-2\upsilon$ approaches zero. Also for the Nonlinear Elastic (Hyperbolic), SIGMA/W uses the formulation presented by (Duncan and Chang, 1970) for calculating the soil modulus. In this method, the stress-strain curve is hyperbolic and the soil modulus is a function of the confining stress and the shear stress that a soil is experiencing. This nonlinear material model is attractive since it requires soil properties can be resulted quite readily from triaxial tests or the literature (Duncan *et al.*, 1980).

RESULTS AND DISCUSSION

Embankment dams during construction and operation are exposed to a variety of stresses that should be designed and implemented safe to withstand these stresses. Different researchers and engineers have already introduced various methods to analyze the stability of the slope of the embankment or rock-fill dam that can be divided into two general methods: limiting equilibrium and stress-strain. In stress- strain method, stresses and strains caused by dam in different parts of the body and foundation of embankment dam are analyzed and according to it, while preparing a picture of the behavior of the dam, confidence coefficient on the most potential rupture surface is determined by comparing the mobilized shear strength.

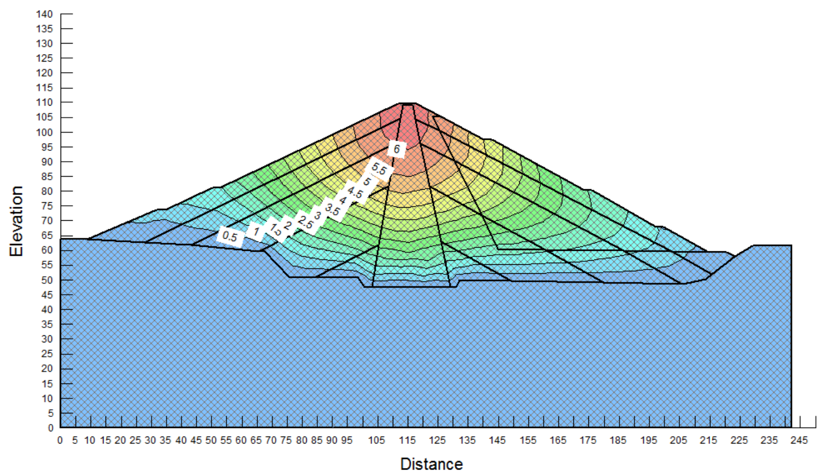

Figure 1: Maximum displacement contour of 62 m dam

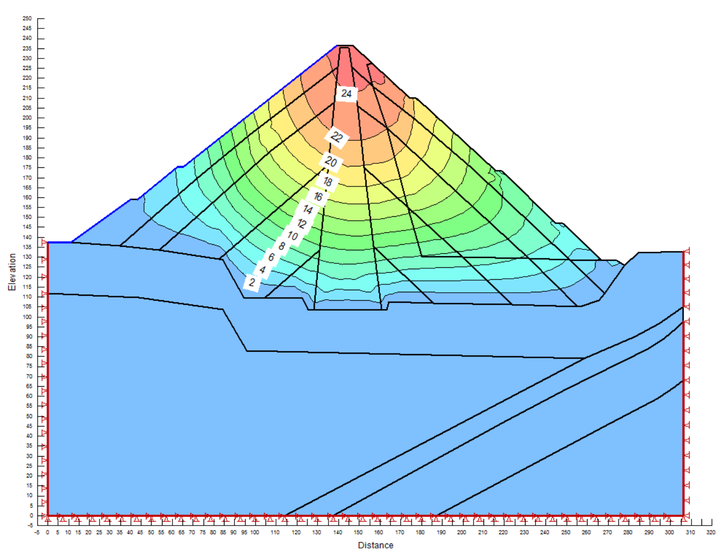

Figure 2: Maximum displacement contour of 133 m dam

Deformation caused in an embankment dam can be divided into three groups: (1) the deformation generated during the construction period. (2) The deformation caused by reservoir impoundment. (3) Long-term deformations caused by the consolidation and creep. Always before impounding, due to the decrease in the pore water pressure distribution, dam has more confidence coefficient than any other dam that's why the construction time in stress - strain analysis is neglected. However, upon the complement of construction of the dam and passage of required time, it's the time for the initial catchment. In heterogeneous dams, the difference between the motions of different materials may occur during the dam impoundment. So this step is very important. Two types of deformation may occur in embankment dams in catchment stage: 1 - Deformation due to the increased water load on the body. 2. Deformation caused by destruction of soil structure in upstream crust due to flooding. In this stage, leakage in the dam body and foundation will be established and they will be consolidated over time. Thus the analysis in this stage is also very important. For this reason, the stress - strain analysis is done at this stage.

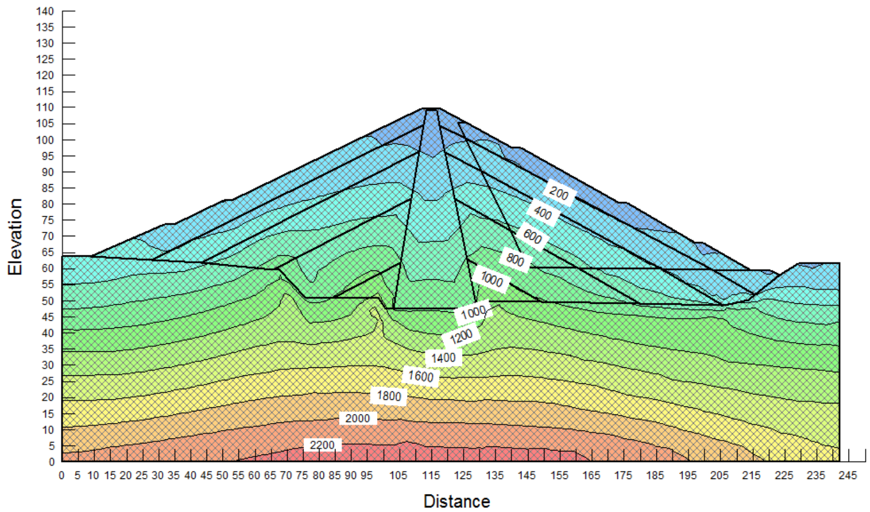

Figure 3: Maximum stress contour of the 62 meters dam

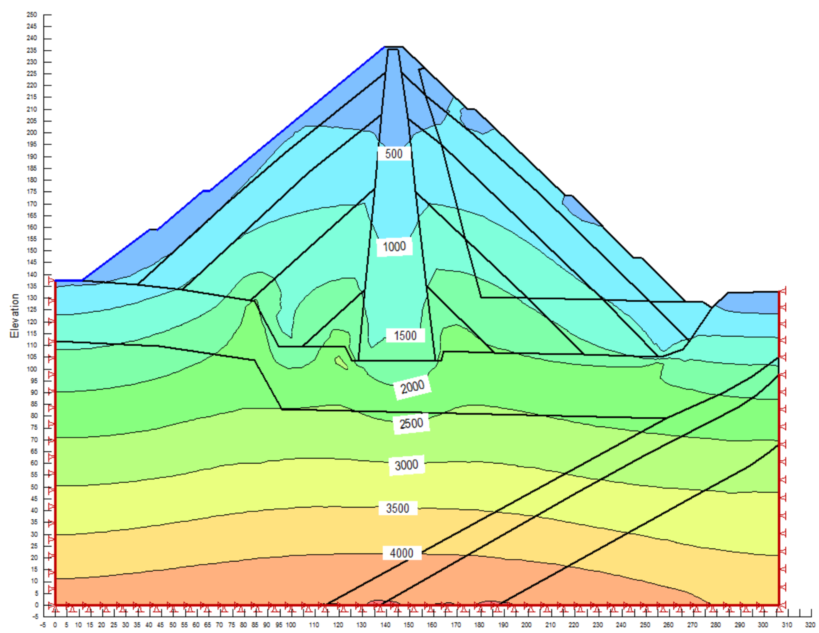

Figure 4: Maximum stress contour of 133 meters dam

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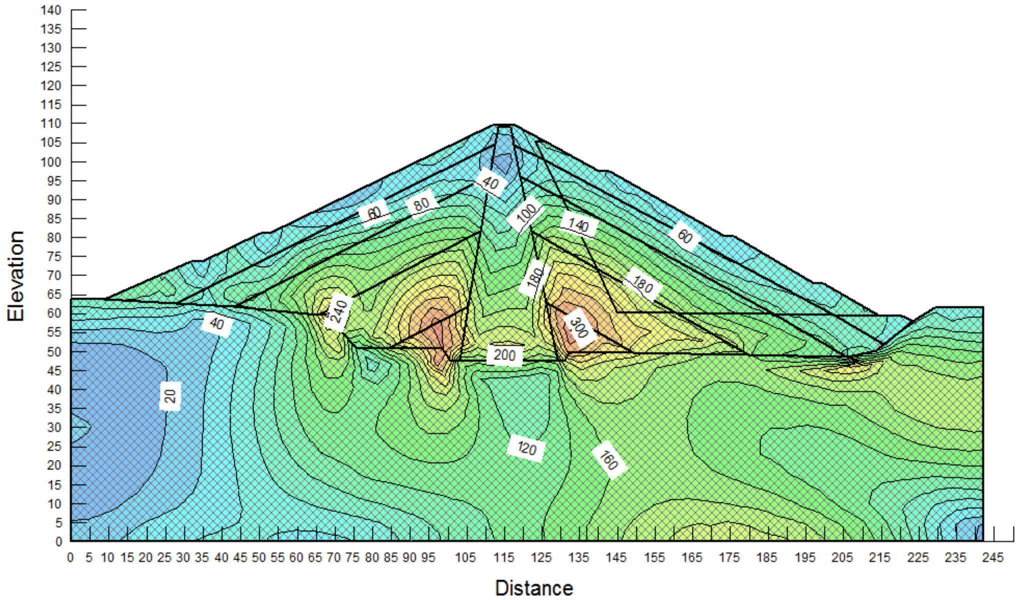

Figure 5: Contour of maximum shear stress on the 62 meters dam

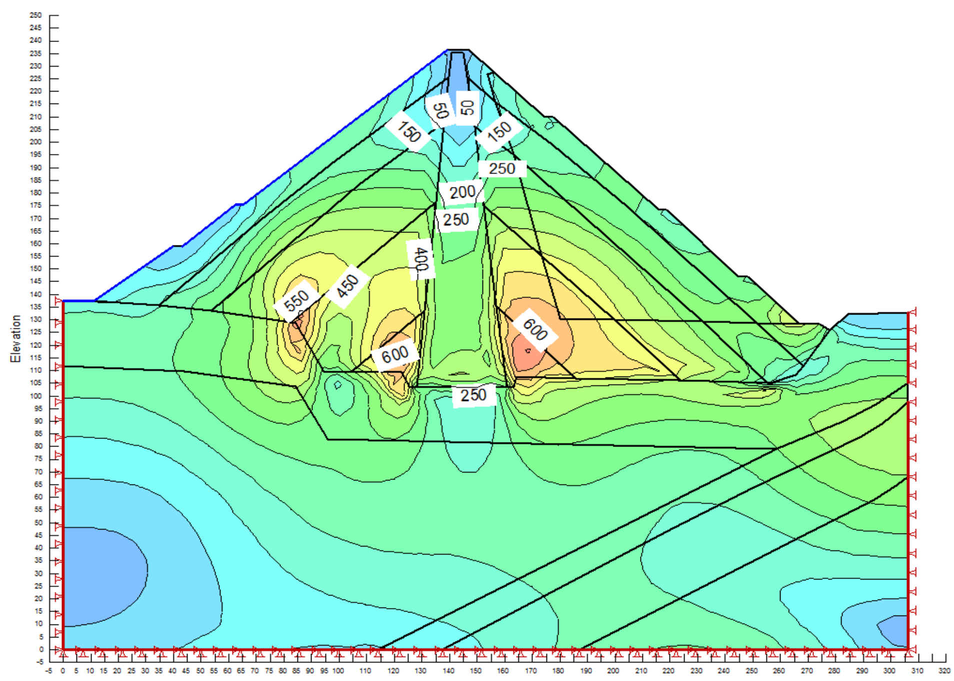

Figure 6: **Contour of maximum shear stress on the 133 meters dam**

In Figure 1 and 2 general displacements of both dams are shown. The maximum displacement in 62 m dam, in horizontal direction is 1.6 meter and in the vertical direction is equal to -6.14 meter that the negative displacement shown the accuracy of calculations, because the pressure was imposed to the upper crust and this pressure is downward and dam displacement should be downward. In 133m dam, the largest displacement in the horizontal direction is 6.22 meter and in vertical direction is -24.55 meter. As was observed, displacement in the vertical direction is more than the horizontal direction. It can be observed that the maximum displacement in both dams is occurred in top of the dams near the crest and also the minimum displacement is occurred in lowest part of the dams.

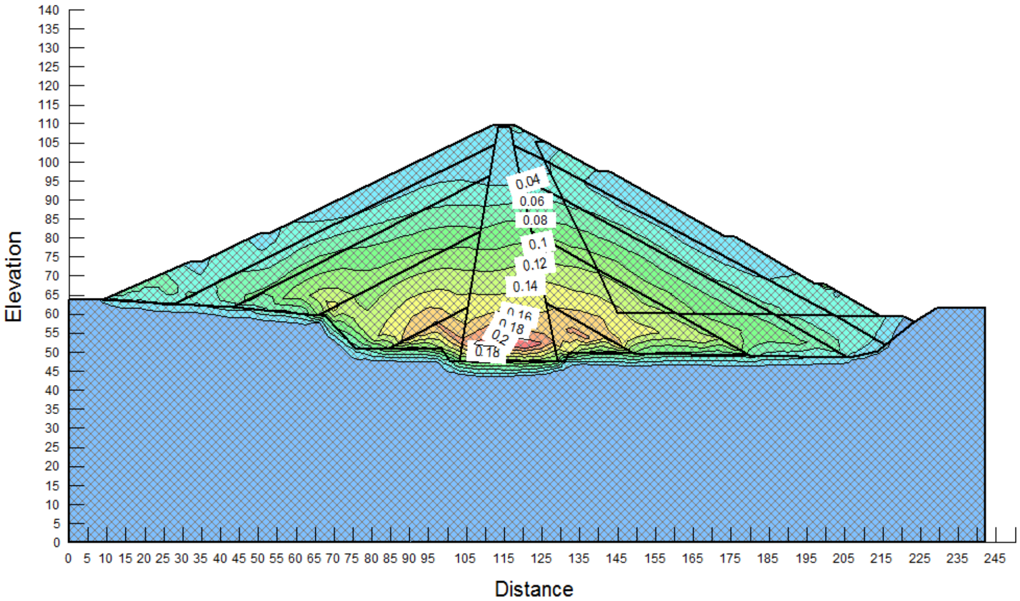

Figure 7: Contour of maximum strain on the 62 meters dam

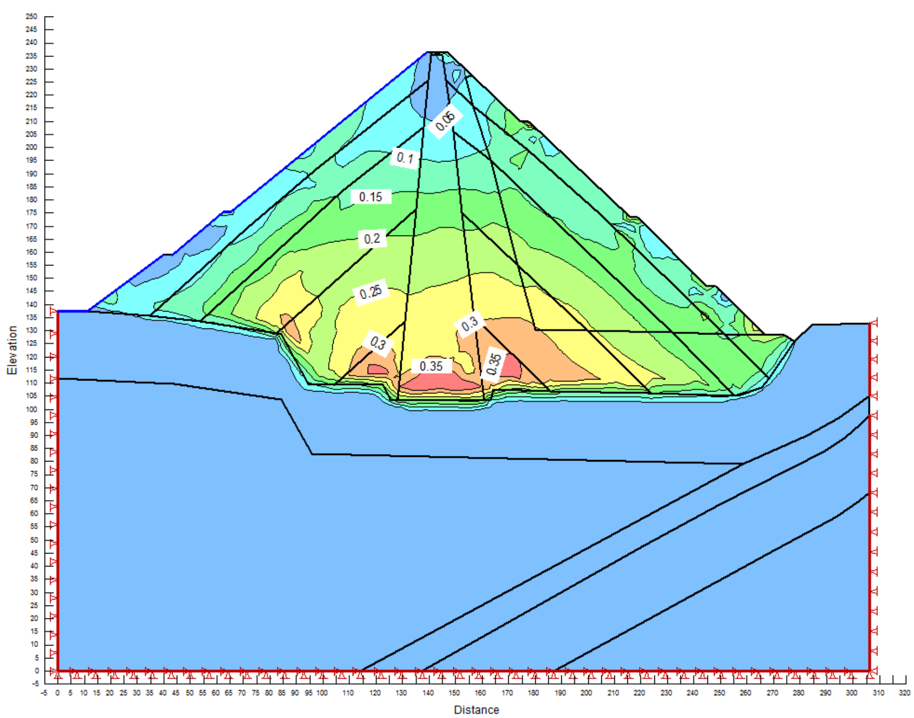

Figure 8: Contour of maximum strain on the 133 meters dam

In Figure 3 and 4, stress contour of both dams is shown. In 62 m dam in the horizontal direction the maximum stress is 2193 kpa and in the vertical direction, the maximum stress is equal to 2286 kpa. In 133 m dam, in the horizontal direction, the maximum stress is 4327 kpa and in the vertical direction, the maximum stress is equal to 4514 kpa. Stress caused in the vertical direction is more than the horizontal direction. It can be observed that the maximum of total stress in both dams is occurred in the foundation of the dams and in the lowest part of dam and also the minimum of stress is occurred in highest part of the dams.

In Figure 5 and 6, shear stress contour of both dams is shown. In both dams it has been observed that the maximum shear stress is achieved in near of the core which is contoured with red. And also minimum shear stress is achieved in top of the dam, in both dams.
In Figure 7 and 8, strain contour of both dams is shown. In 62 m dam in the horizontal direction the maximum strain is 0.087 and in the vertical direction, the maximum strain is equal to 0.2. In 133 m dam, in the horizontal direction, the maximum strain is 0.334 and in the vertical direction, the maximum strain is equal to 0.4., the maximum strain is obtained in bottom of core, which is shown in both dams by red color. Also the minimum strain is achieved in top of the dams in blue color.

Table 2: Comparing the maximum result of the 62 and 133 meters dams

Parameter	62 meter	133 meter	Difference value
Displacement (m)	6.25	25.1	18.85
Stress total (kpa)	2334	4543	2209
strain	0.21	0.4	0.19
Shear stress (kpa)	320.8	655.6	334.8

Conclusion

In this study, two dams with the completely identical characteristics and different heights were modeled using software and the effects of height on parameters obtained from the stress - strain analysis was examined. The study was done on two heterogeneous dams that the features of materials allocated for both are considered as identical. It can be observed that the maximum displacement in both dams is occurred in top of the dams near the crest and also the minimum displacement is occurred in lowest part of the core dams. Of course, this is due to the presence of water in the reservoir that incurs a high pressure on the bottom side of the dam.
With a more accurate view to the results obtained in the area of displacement, it is clear that the displacement of dam with higher height was more than the dam with shorter height that this is due to the extra weight of the dam with higher height. So it is better to use materials with lower specific weight in case of constructing dam with high height. Also the maximum strain is obtained in bottom of core and also the minimum strain is achieved in top of the dams. It can be observed that the maximum of total stress in both dams is occurred in the foundation of the dams, in the lowest part of dam and also the minimum of stress is occurred in highest part of the dams. In both dams it has been observed that the maximum shear stress is achieved in near of the core and also minimum shear stress is achieved in top of the dam, in both dams. Examining the amount of total stress, strain and shear stress on the dam, it is also concluded that stresses and strains in higher dam have greater values than shorter dam that this is also indicating the role of height in increasing the stresses and strains created in the dam. Also the parameters of stress, strain and displacement in both dams vertically are greater than displacement in horizontal direction.

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