

Sensitivity Analysis of Symmetrical Hard fill Dams

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Abstract: In this paper, parametric study and sensitivity analysis of symmetrical trapezoidal hard fill dams are carried out. Finite Element Method is used to analyze the stresses in dam body and the basement under different cases. Different dam slopes and various rigidities of foundation and dam body are considered to study the effects of these factors on the behavior of the dam. The results show that generally increasing in foundation modulus of elasticity results in decreasing in dam body stresses. In contrast, the effect of dam body modulus of elasticity is vice versa. The results indicate that, when downstream slope is lower than 0.7H: 1V, there is big compressive stresses close to dam toe. According to sensitivity analysis, changes in downstream slope and changes in upstream and downstream slopes simultaneously are the main parameters affecting the maximum principal tensile, compressive stress of dam body and maximum compressive stress at dam basement.

Key words: Parametric • Sensitivity • Finite element method • Hard fill

INTRODUCTION

Parametric studies on materials and safety of dams were done in different parts of the world [1, 2]. The concept of hard fill is not new. In other guises it can be termed soil cement sand and Cement Sand Gravel (CSG). The use of soil cement for upstream wave protection on embankment dams was pioneered by the USBR on the bonny reservoir in Colorado, USA, in 1951 [2]. A trapezoidal CSG dam is a new type of a dam that combines a trapezoidal dam and CSG materials. The maximum compressive stress in a trapezoidal concrete gravity dam is relatively low compared with other concrete dams. This means that a trapezoidal concrete dam can utilize even CSG as its dam body material [3]. According to preceding findings, slope stability analysis gave a minimum safety factor of 1.31 and 1.22 using effective stress analysis (ESA) and effective stress analysis (USA) methods, respectively [4, 5]. In addition, there are further studies on the safety of symmetrical hard fill dams. The findings indicate that the hard fill dam has greater safety than gravity dam [2]. The concept of the faced

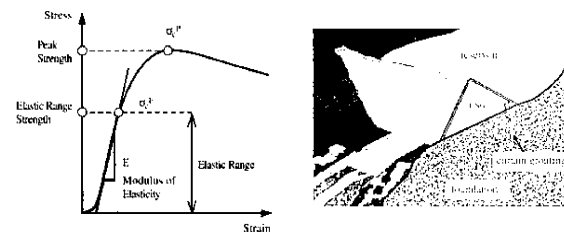


Fig. 1: Hard Fill dam characteristics

symmetrical hard-fill dam, or trapezoidal CSG dam as it is termed in Japan, is explored more fully in ICOLD Bulletin 117 [6].

In this paper, using Finite Element Method, the effect of different parameters on the safety of symmetrical hard fill dams is investigated. In addition, the sensitivity analysis of this type of dams is carried out. Different dam slopes and various rigidities of dam body and foundation are considered to study the effects of these factors on the behavior of the dam.

Features of Hard fill Dams: Hard fill is a material made by adding little cement to rock like material such as riverbed

gravel or excavation muck. Figure 1 shows the typical stress strain curve of hard fill and a pre figure of hard fill dam, which is symmetrical trapezoid shaped or approximately symmetrical [6, 7]. The dam slope can be determined according to some facts such as foundation condition, height of the dam, performance of the filling material and so on.

Finite Element Method: In this study, Constant Strain Triangle element is used [8]. Equation 1 is used to calculate the element stresses. The calculated stress is used as the value at the center of each element.

$$\sigma = DBq \quad (1)$$

Where D is material property matrix, B is element strain displacement matrix and q is element nodal displacement from the global displacements vector Q. For plane strain conditions, the material property matrix is given by

$$D = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & 1-2\nu/2 \end{bmatrix} \quad (2)$$

Element strain displacement matrix is given by

$$B = \frac{1}{\det J} \begin{bmatrix} y_{23} & 0 & y_{31} & 0 & y_{12} & 0 \\ 0 & x_{32} & 0 & x_{13} & 0 & x_{21} \\ x_{32} & y_{23} & x_{13} & y_{31} & x_{21} & y_{12} \end{bmatrix} \quad (3)$$

In which, J is jacobian matrix and the points 1, 2 and 3 are ordered in a counterclockwise manner. Jacobian matrix is given by

$$J = \begin{bmatrix} x_{13} & y_{13} \\ x_{23} & y_{23} \end{bmatrix} \quad (4)$$

Global displacements vector Q is given by

$$KQ = F \quad (5)$$

In which, K and F are modified stiffness matrix and force vector, respectively. The global stiffness matrix K is formed using element stiffness matrix k_e which is given by

$$k_e = t_e A_e B^T DB \quad (6)$$

In which, t_e and A_e are element thickness and element area, respectively. Hard fill and foundation are assumed as elastic material.

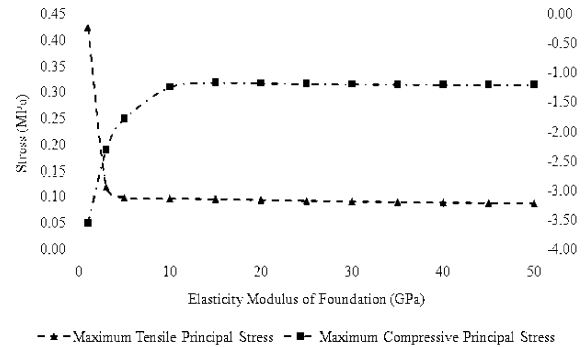


Fig. 2: Influence of foundation modulus of elasticity on body principal stresses

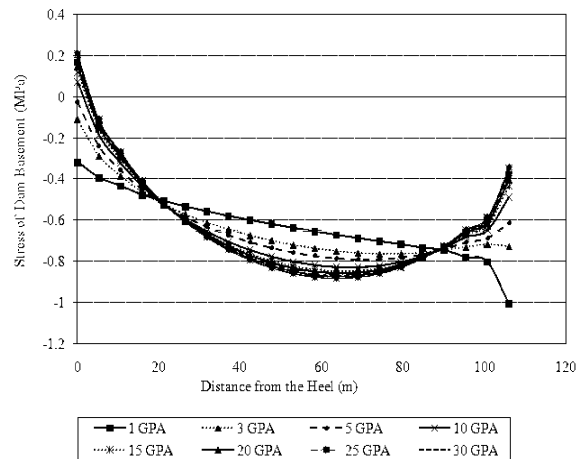


Fig. 3: Influence of foundation modulus of elasticity on stress distribution at dam basement

The Impact of the Rigidity: The stress distribution of a dam is based on the values of all geometrical and mechanical properties of materials. Variation material in rigidity of dam body and foundation affect the response of the dam. Therefore, impacts of dam body and foundation rigidity are evaluated. First of all, assuming that the foundation is uniform foundation and keeping the modulus of elasticity of dam equal to 5GPa, the effect of various modulus of elasticity of foundation from 1 to 50GPa is investigated. Figure 2 shows relationship between the maximum and minimum value of principal stresses and the foundation modulus of elasticity. Also, the relationship between stress distribution at dam basement and the elasticity modulus of foundation is illustrated in Figure 3.

Then, by changing the elasticity modulus of the dam body from 1.5 to 10 while the foundation modulus of elasticity is 3GPa, the study of distribution of dam stress is carried out. As it can be seen from Figure 4, the effect of the modulus of the dam body is really considerable.

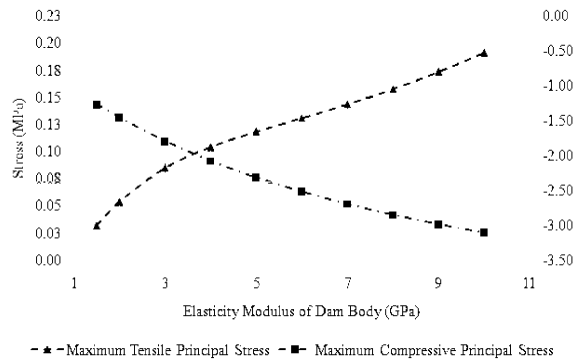


Fig. 4: Influence of foundation modulus of dam body on body principal stresses

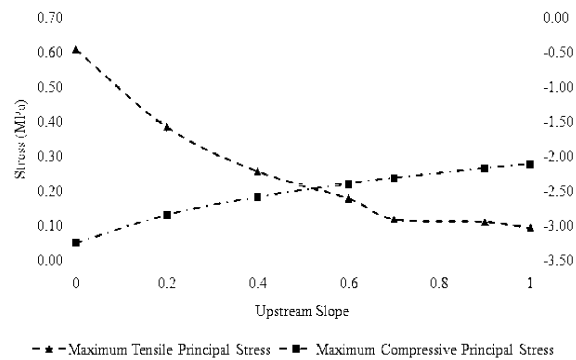


Fig. 5: Influence of upstream slope on body principal stresses

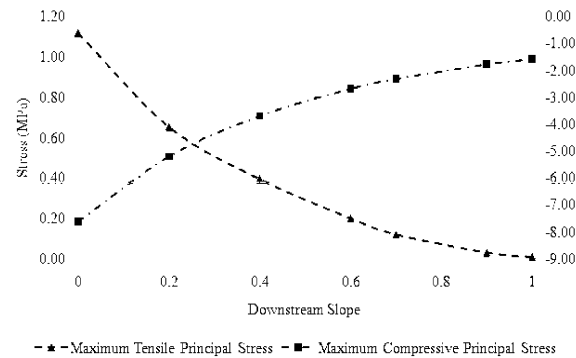


Fig. 6: Influence of downstream slope on body principal stresses

Figure 2 indicates that when foundation modulus of elasticity is lower than 10GPa, increasing in the modulus of elasticity results in decreasing in both maximum principal compressive and tensile stresses in dam body. In contrast, for the elasticity modulus of foundation bigger than 10GPa, there are no considerable changes in the stresses. However, as it can be seen from Figure 4, the bigger dam modulus of elasticity is, the bigger dam stresses are.

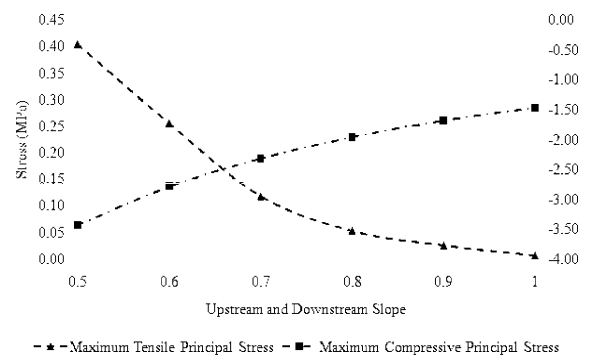


Fig. 7: Influence of upstream and downstream slope on body principal stresses

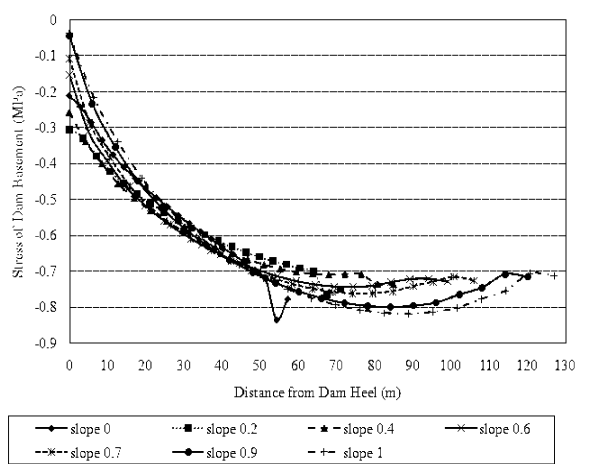


Fig. 8: Influence of upstream slope on stresses distribution at basement

Figure 3 illustrates that both maximum principal tensile and compressive stress at dam basement become bigger when there is increasing in elasticity modulus of foundation, while stress distribution at dam basement remains steady for the foundation modulus of elasticity bigger than 10 GPa.

The Impact of Dam Slope Gradient on Dam Stress:

The influences of the dam slopes on the dam principal stresses and stress distribution at the basement of dam are analyzed. In the first case, upstream slope is changed from 0.2H: 1V to 0.9H: 1V while the downstream slope is 0.7H: 1V. Downstream slope's effect on the stresses is investigated when upstream slope is 0.7H: 1V. Also, the impacts of the both upstream and downstream slopes are analyzed. In all cases elasticity modulus of dam body and foundation are equal to 5GPa and 3GPa, respectively. Results are shown in Figure 5 to Figure 10.

Figure 5 to Figure 7 show that when the slopes are gentler, both maximum principal tensile and compressive

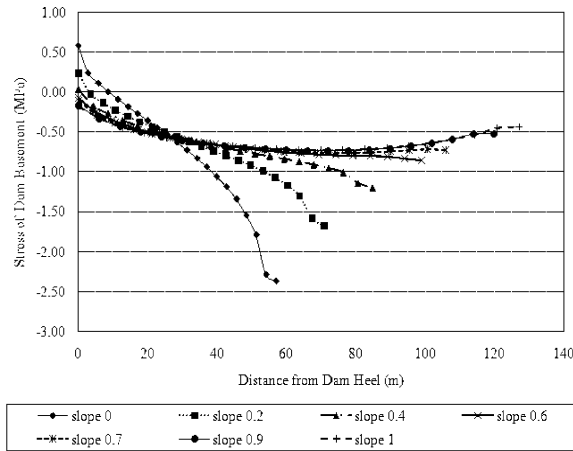


Fig. 9: Influence of downstream slope on stresses distribution at basement

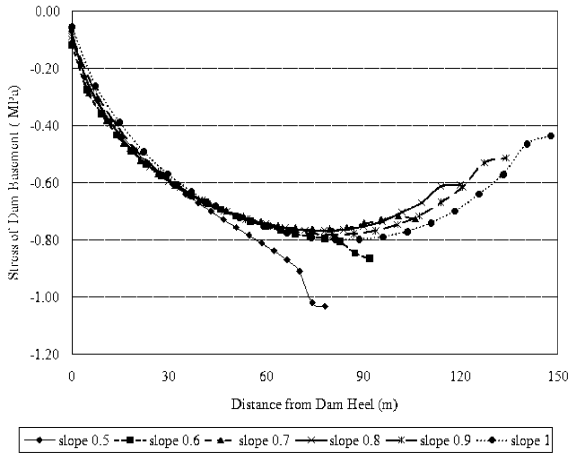


Fig. 10: Influence of upstream and downstream slope on stresses distribution at basement

stress of dam body are decreased. As it can be seen from Figure 9 and Figure 10, when downstream slope is lower than 0.7H: 1V, there are big compressive stresses close to dam toe. Comparing Figure 8 to Figure 10, it is clear that the best slope for upstream and downstream is 0.7H: 1V.

Sensitivity Analysis: Sensitivity analysis is the study of how the variation in the output can be apportioned, qualitatively or quantitatively, to different sources of variation in the input [9]. Put another way, it is a technique for systematically changing parameters in a model to determine the effects of such changes. Sensitivity analysis can be useful for a range of purposes, including increasing understanding and quantification of the system, understanding relationships between input and output variables and supporting decision makers [10].

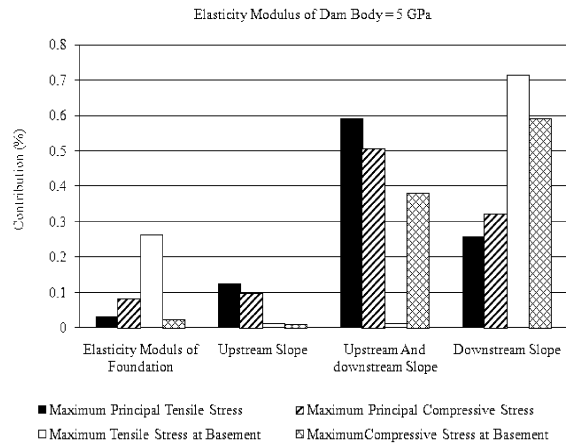


Fig. 11: Contributions of variance in the dam stresses when elasticity modulus of dam body is 5GPa

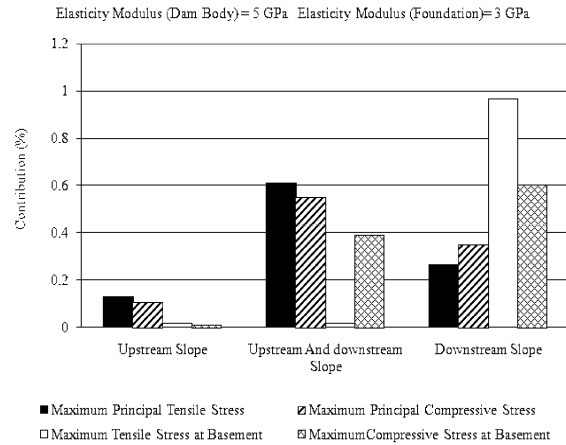


Fig. 12: Contributions of variance in the dam stresses when elasticity modulus of dam body and foundation are 5GPa and 3GPa, respectively

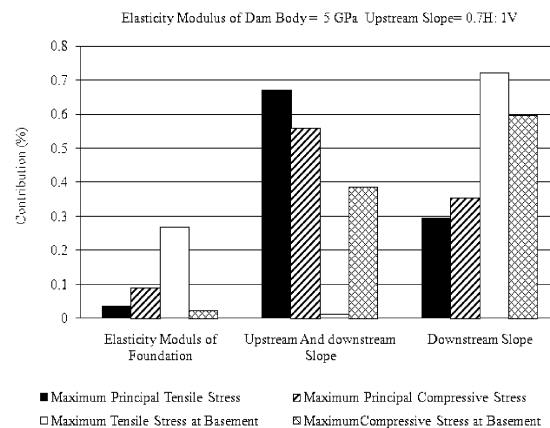


Fig. 13: Contributions of variance in the dam stresses when elasticity modulus of dam body is 5 GPa and upstream slope is 0.7H: 1V

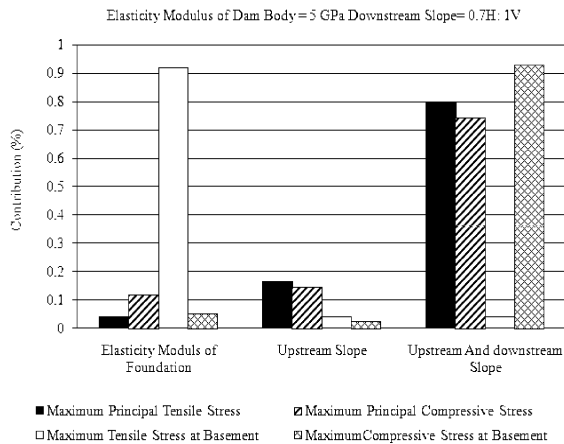


Fig. 14: Contributions of variance in the dam stresses when elasticity modulus of dam body is 5GPa and downstream slope is 0.7H: 1V

Figure 11 to Figure 14 show the relative contributions of variation in variables to the changes in the dam stresses. Figure 11 shows the contributions when the dam body modulus of elasticity takes the value of 5GPa. As it can be seen from the figures, changes in downstream slope and changes in upstream and downstream slopes in the same time are the main parameters affecting the maximum principal tensile, compressive stress of dam body and maximum compressive stress at dam basement. In addition, the foundation modulus of elasticity and downstream slope are the most important parameters affecting maximum tensile stress at dam basement.

Also, as it is shown in Figure 11 and Figure 14, the upstream slope and the foundation modulus of elasticity approximately have similar effects on the maximum principal stress and maximum compressive stress at dam basement.

CONCLUSION

This study shows the effects of geometrical and mechanical properties of dam body and mechanical properties of foundation on the dam behaviors. Parametric study and sensitivity analysis are carried out. Finite Element Method is used to analyze the stresses in dam body and the dam basement. Different dam slopes and various rigidities of dam body and foundation are considered to study the effects of these factors on the behavior of the dam. In general the results show that:

- When foundation modulus of elasticity is lower than 10GPa, increasing in the modulus of elasticity results in decreasing in both principal maximum compressive and tensile stresses in dam body. However, for the elasticity modulus bigger than 10GPa there are no considerable changes in the stresses.
- The bigger dam modulus of elasticity is, the bigger dam stresses are.
- Both maximum tensile and compressive stresses at dam basement become bigger when there is increasing in elasticity modulus of foundation. While stress distribution at dam basement remains steady for the foundation modulus of elasticity bigger than 10 GPa.
- When the slopes are gentler, both maximum principal tensile and compressive stress of dam body are decreased. In contrast, when downstream slope is lower than 0.7H: 1V, there are big compressive stresses close to dam toe. Considering of economic factors, the best slopes for upstream and downstream are 0.7H: 1V.
- Changes in downstream slope and simultaneously changes in upstream and downstream slopes are the main parameters affecting the maximum principal tensile and compressive stress of dam body and maximum compressive stress at dam basement. While the foundation modulus of elasticity and downstream slope are the most important parameter affecting maximum tensile stress at dam basement.
- The upstream slope and the foundation modulus of elasticity approximately have similar effects on the maximum principal stress and maximum compressive stress at dam basement.

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