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Parametric Studies on the Structural Safety of Kahir Dam

Zaniar Tokmechi

Islamic Azad University, Sanandaj Branch, Sanandaj, Iran

Abstract: In this paper, parametric optimization study of Kahir dam was carried out. Finite Element method was used to analyze the stresses in dam body and the basement. Different dam slopes and different foundations rigidity are considered to study the effects of these factors on the behaviors of the dam and its safety. Results show that the symmetrical trapezoid shaped hard fill dam has advantages of high safety. It is clear from results that If Kahir hard fill dam must be constructed on the non homogenous foundation, the heel side weaker dam foundation is more favorable. Results show that the gentler dam slopes are, the smaller the stress is. And also, the best upstream and downstream slopes are both 0.7H: 1V. It is clear from results that the hard fill dam has great safety.

Key words: Kahir dam · Finite element method · Parametric · Slopes · Rigidity

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 dams 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 and findings indicate that the hard fill dam has greater safety than gravity dam [6]. The concept of the faced symmetrical hard fill dam, or trapezoidal CSG dam as it is termed in Japan, is explored more fully in ICOLD Bulletin 117 [7].

The Kahir dam will be the first faced symmetrical hard fill dam to be constructed in Southeast Iran. Kahir is 53 m high, 370 m long at the crest and contain approximately 510000 m^3 of concrete. It is a symmetrical trapezoid shaped dam [6].

Considerable safety of hydro structures such as dams [8, 9] adds the study of risky. In this paper, parametric optimization study of Kahir dam was carried out. Finite Element method was used to analyze the stresses in dam body and the basement. Different dam slopes and different foundations rigidity are considered to study the effects of these factors on the behaviors of the dam and its safety.

Features of Kahir Hard Fill Dam: 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 [2]. 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. Figure 2 shows typical profile of Kahir dam, which is symmetrical trapezoid shaped.

In this study, hard fill and foundation are assumed as elastic material. Material properties were assumed as the constant values shown in table 1. In the results, the positive value means tensile stress, the negative value means compressive stress, σ_1 signifies the first principal stress on the tensile side and σ_3 Signifies the third principal stress on the compressive side.

Fem Analysis: In this study, Constant Strain Triangle element is used [10]. Equation 1 is used to calculate the element stresses. The calculated stress is used as the value at the center of each element.

Corresponding Author: Zaniar Tokmechi, Islamic Azad University, Sanandaj Branch, Sanandaj, Iran,
Tel: +98-918-873-1933, Fax: +98-871-3229437, E-mail: z.tokmechi@gmail.com

Table 1: Materials properties

Material	Modulus of elasticity (GPa)	Poisson's ratio	Unit mass (kg/m^3)
Hard fill	5	0.25	2200
Foundation	3	0.3	---

$$\sigma = DBq \tag{1}$$

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

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

Element strain displacement matrix is given by

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

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

$$J = \begin{bmatrix} x_{13} & y_{13} \\ x_{23} & y_{23} \end{bmatrix} \tag{4}$$

Global displacements vector Q is given by

$$KQ = F \tag{5}$$

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

$$k^e = t_e A_e B^T DB \tag{6}$$

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

The Demand to Foundation Strength: Considering empty and full reservoir stress, Fig. 3 shows the distribution of vertical normal stress at bottom of the dam. It reveals that there is little variation in the stress according to the location and various loading condition at bottom of the Kahir dam. The maximum compressive stress at basement of Kahir trapezoid shape dam is only -0.63 MPa. It is one of the advantages of this dam compares to conventional gravity dams.

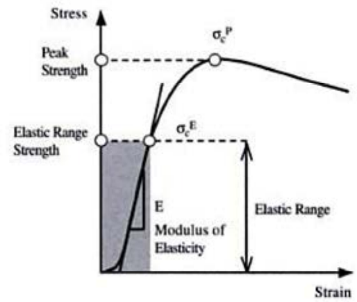

Fig. 1: Typical stress-strain curve of hard fill

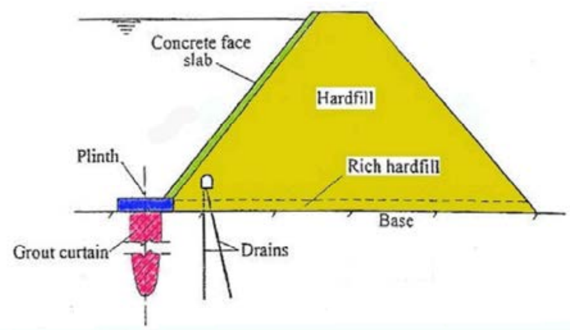

Fig. 2: Typical profile of Kahir dam

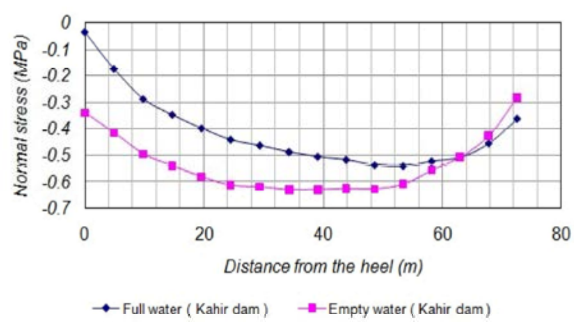

Fig. 3: Distribution on normal stress at basement (Pa)

The Impact of the Rigidity of Foundation: Assuming that the foundation is uniform foundation and keeping the modulus of elasticity of dam equal to 5GPa, the modulus of elasticity of foundation changes from 1 to 30 GPa. Fig. 4 shows relationship between the maximum and minimum values of principal stresses and the foundation modulus of elasticity.

If the foundation is rigid, there has no notable effect on dam stress. The result shows that Kahir hard fill dam adapts to the weak dam foundation. As the accretion of modulus of elasticity of dam foundation, it will augment the security of dam body.

Table 2: Material properties of two kinds of rock

Condition	Heel side Modulusof elasticity	Toe side Modulusof elasticity	Ratio
1	15 (GPa)	3 (GPa)	5:1
2	30	3	10:1
3	3	15	1:5
4	3	30	1:10

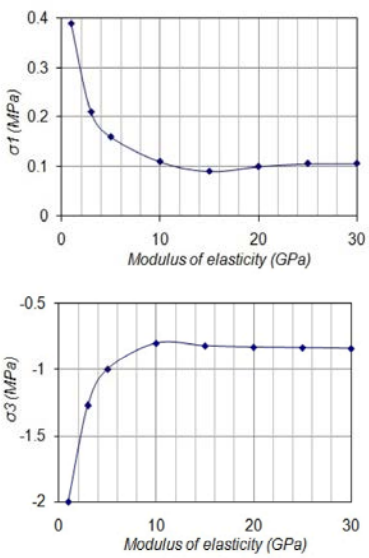

Fig. 4: Relationship between maximum and minimum principal stress and foundation Modulus of elasticity

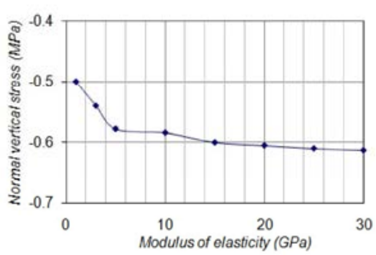

Fig. 5: Relationship between normal vertical stress and foundation Modulus of elasticity

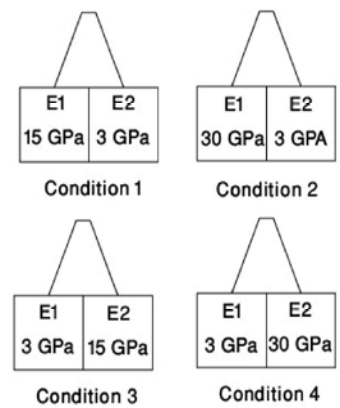

Fig. 6: Non homogeneous conditions of foundation

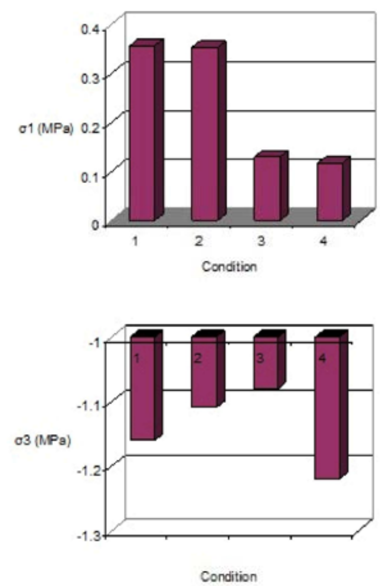

Fig. 7: Relationship between maximum and minimum principal stress and non homogeneous of foundation

The Impact of the non Homogeneous of Foundation: It is often encountered uneven foundation in many engineering. These uneven foundation cases may affect the dam body stresses. Assuming two kinds of rock in foundation, the material properties of these two kinds of rock are shown in table 2.

Fig. 6 shows the impact of the heterogeneity of ground on the dam stress. It is shown that the toe side weaker dam foundation will develop bigger tensile principal stress on dam body. While, if the heel side dam foundation is weaker, it would develop small tensile stress on dam body. Compared, the heel side weaker dam foundation is more favorable.

Fig. 7 shows the relationship between maximum and minimum principal stresses and non homogeneous of foundation. Also, Fig. 8 shows the relationship between the normal vertical stress at the basement of the Kahir dam and non homogeneous of foundation.

According to Fig.7 and 8, it is clear that the toe side weaker dam foundation will develop tensile stress at dam heel. If the heel side dam foundation is weaker, it would

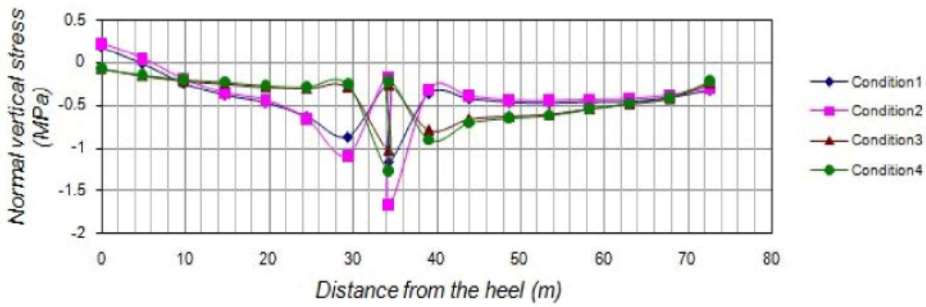

Fig. 8: Relationship between normal vertical stress and non homogeneous of foundation

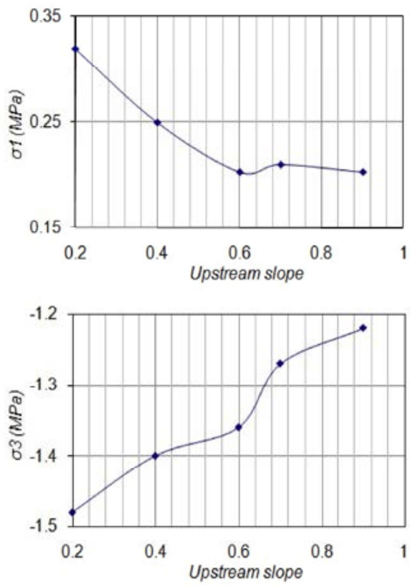

Fig. 9: Relationship between maximum and minimum principal stresses and upstream slope

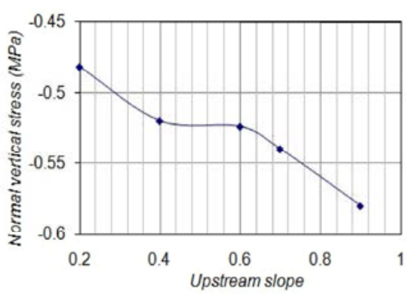

Fig. 10: Relationship between the normal vertical stresses and the upstream slope

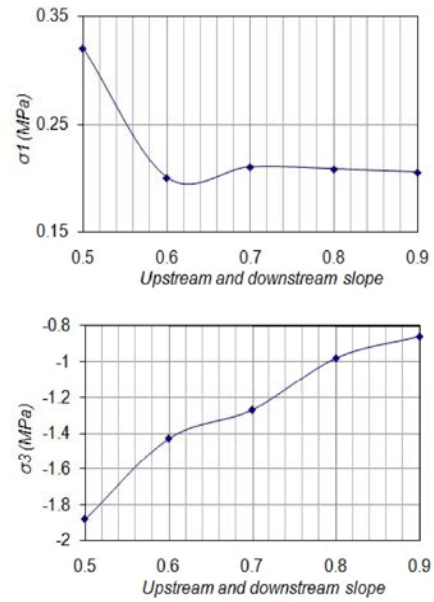

Fig. 11: Relationship between maximum and minimum principal stress and upstream and downstream slopes

not develop tensile stress and the stress at dam heel improved. Compared, the heel side weaker dam foundation is more favorable.

The Impact of Upstream Slope: Assuming the downstream slope is 0.7H: 1V. The upstream slope has been changed from 0.2H: 1V to 0.9H: 1V. Fig. 9 shows the relationship between the maximum and minimum values of principal stresses and the upstream slope. It shows that the gentler slopes of upstream slope are, the smaller the stress is.

Fig. 10 shows the relationship between the normal vertical stresses and the upstream slope. It shows that the gentler slope of upstream slope is, the bigger the stress is.

The Impact of Upstream and Downstream Slope: Assuming that the dam is symmetrical, upstream and downstream slopes change simultaneously, such as 0.5H: 1V, 0.6H: 1V, 0.7H: 1V, 0.8H: 1V and 0.9H: 1V.

Fig. 11 shows relationship between the maximum and minimum values of principal stresses and the upstream and downstream slopes. It shows that gentler the slopes

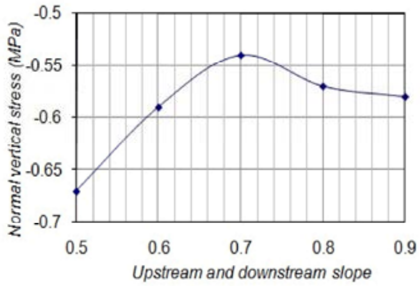

Fig. 12: Relationship between normal vertical stress and upstream and downstream slopes

of upstream and downstream slopes are, the smaller the stress is. Consideration of economic factors, the best upstream and downstream slopes are both 0.7H: 1V.

Fig. 12 shows the relationship between the normal vertical stresses and the upstream and downstream slopes. It shows that the gentler dam slopes are, the smaller the stress is.

CONCLUSION

The Kahir dam will be the first faced symmetrical hard fill dam to be constructed in Southeast Iran. Kahir is 53 m high, 370 m long at the crest and contain approximately 510000 m^3 of concrete. It is a symmetrical trapezoid shaped dam with a concrete impervious face in the upstream. From the viewpoint of structural stability, the symmetrical trapezoid shaped hard fill dams should have advantages of high safety.

In this paper, parametric optimization study of Kahir dam was carried out. Finite Element method was used to analyze the stresses in dam body and the basement. There are some conclusions in the following:

- The maximum compressive stress at basement of Kahir trapezoid shape dam is only -0.63 MPa. It is one of the advantages of this dam in comparison with conventional gravity dams.
- There is little variation in the basement stress according to the location and various loading condition at bottom of the Kahir dam.
- The result shows that Kahir hard fill dam adapts to the weak dam foundation. As the accretion of modulus of elasticity of dam foundation, it will augment the security of dam body.
- The study and analysis show that Kahir hard fill dam has great safety.
- If Kahir hard-fill dam must be constructed on the uneven foundation, the heel side weaker dam foundation is more favorable.
- The gentler the slopes of upstream and downstream slopes are, the smaller the stress is.
- Considering of economic factors, the upstream and downstream slopes are both 0.7 H: 1 V is the best.

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