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A Comparison on Slope Stability Analysis of Aydoghmoosh Earth Dam by Limit Equilibrium, Finite Element and Finite Difference Methods

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Abstract. In this paper the slope stability of Aydoghmoosh earth dam situated in the north west of Iran is evaluated by various methods of limit equilibrium, finite element and finite difference. Among numerous limit equilibrium methods, Simplified Bishop, Janbu and Spencer are selected so that cover a wide range from simplest to most complicated. The results of all methods are compared together and advantages/disadvantages of them are also discussed.

Introduction

Aydoghmoosh earth dam, which is under construction on Aydoghmoosh River, is located at 25km distance, in the southwest of Miyaneh City, Department of East-Azerbayjan, in the Northwest of Iran (fig. 1).

Fig.1. The loacation map of study area

In this paper the Slope stability of this dam is evaluated by various methods of limit equilibrium, finite element and finite difference.

Geotechnical parameters of Aydoghmoosh Earth Dam[5]

The height of the dam is about 75m and its length of crest is about 350m.
It is an earth dam with an inclined core made of impervious clay. The cross-section of this dam is shown in fig.2.

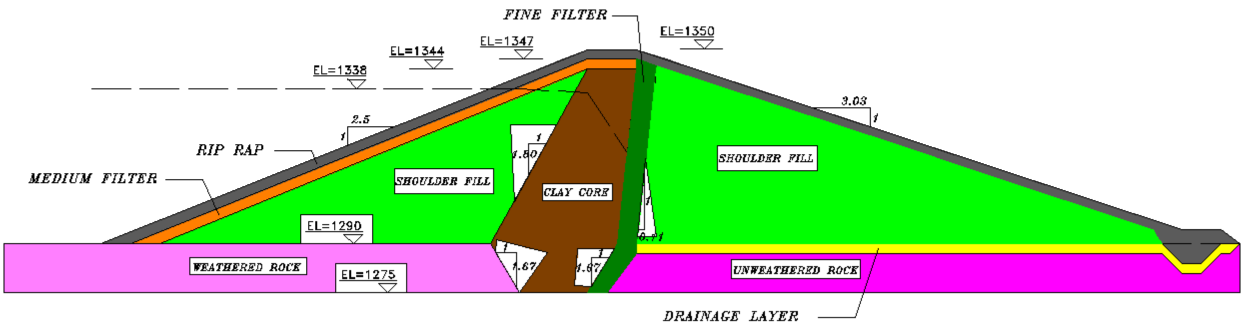

Fig.2. Cross section of Aydoghmoosh Earth Dam

According to the results of the geotechnical study and the tests accomplished in the site and in laboratory, the mechanical characteristics of materials are evaluated. These results are resumed in table 1.

Table 1. Mechanical characteristics of dam materials

Material	$\gamma_{sat}(\frac{KN}{m^3})$	$\gamma_w(\frac{KN}{m^3})$	$C(\frac{KN}{m^2})$	$\emptyset(^\circ)$	$E(\frac{KN}{m^2})$
Rip rap	21	18	0	45	20000
Medium filter	20	19	0	40	20000
Shoulder fill	21	21	10	30	8000
Clay core	21	21	5	21	10000
Fine filter	19	18	0	30	20000
Drainage layer	19	19	0	30	80000
Weathered rock	22	22	1000	0	20000
Unweathered rock	23	23	8000	0	20000

Slope stability analysis of Aydoghmoosh earth dam by Limit Equilibrium Method (LEM) [1,3,9]

Limit Equilibrium Analysis was performed by the programs Slope version 12.01 and Slide version 5.

Slope is an analytical tool for the design of slopes and reinforced soils. The software supports Fellenius, Janbu and simplified Bishop method.

The cross section of Aydoghmoosh earth dam as prepared by the programs Slope is shown in fig.3. The safety factor and sliding surface of an analysis is also shown in this figure.

Fellenius method is not applicable to submereged slopes. Two analysis were performed with the program Slope, one with Simplified Bishop Method and a second with the Janbu method.

Safety factors of 1.494 and 1.270 were obtained with Simplified Bishop and Janbu methods respectively.

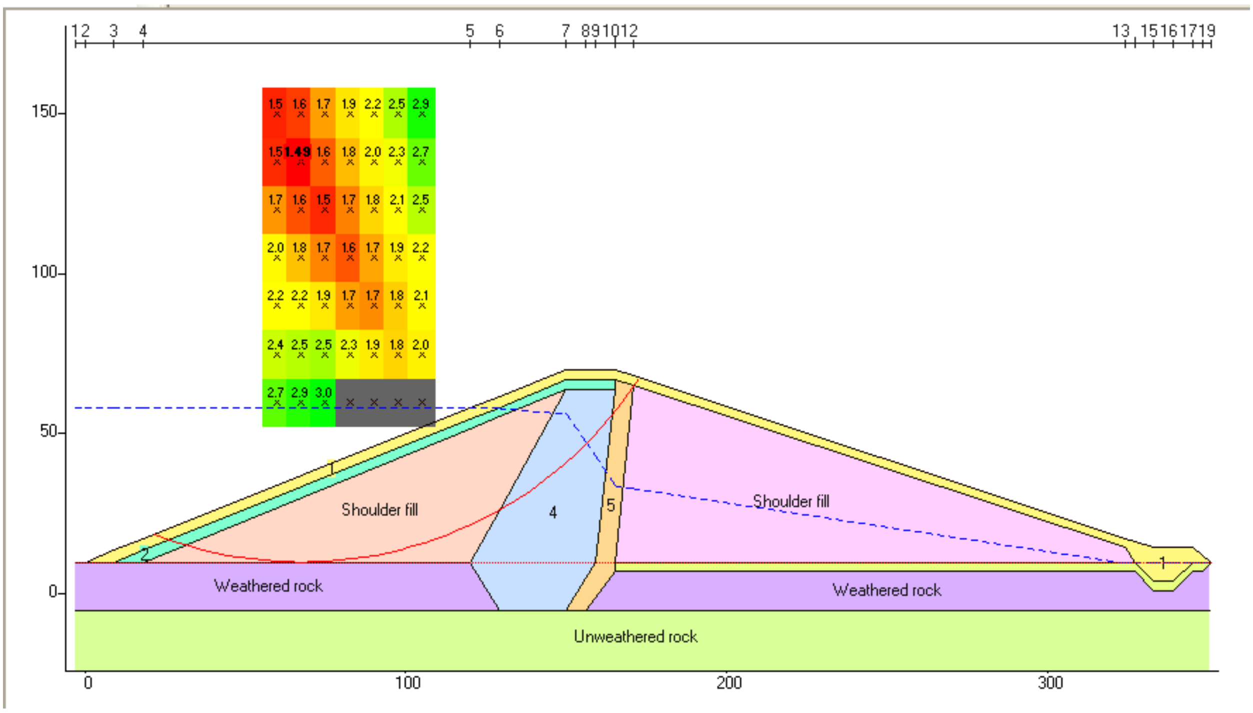

Fig.3. Cross section of Aydoghmoosh earth dam by the programs Slope

Slide is a 2 dimensional stability analysis program that considers geomechanical- geometrics of unstable area and the amount of underground water.

The cross section of Aydoghmoosh earth dam as prepared by the program Slide is also shown in fig.4. The safety factor and sliding surface of an analysis is shown in this figure too.

Two analysis were performed with the program Slide, one with Simplified Bishop Method and a second with the Spencer method.

Safety factors of 1.492 and 1.490 were obtained with Simplified Bishop and Spencer methods respectively that are in full match with the results of the program Slope.

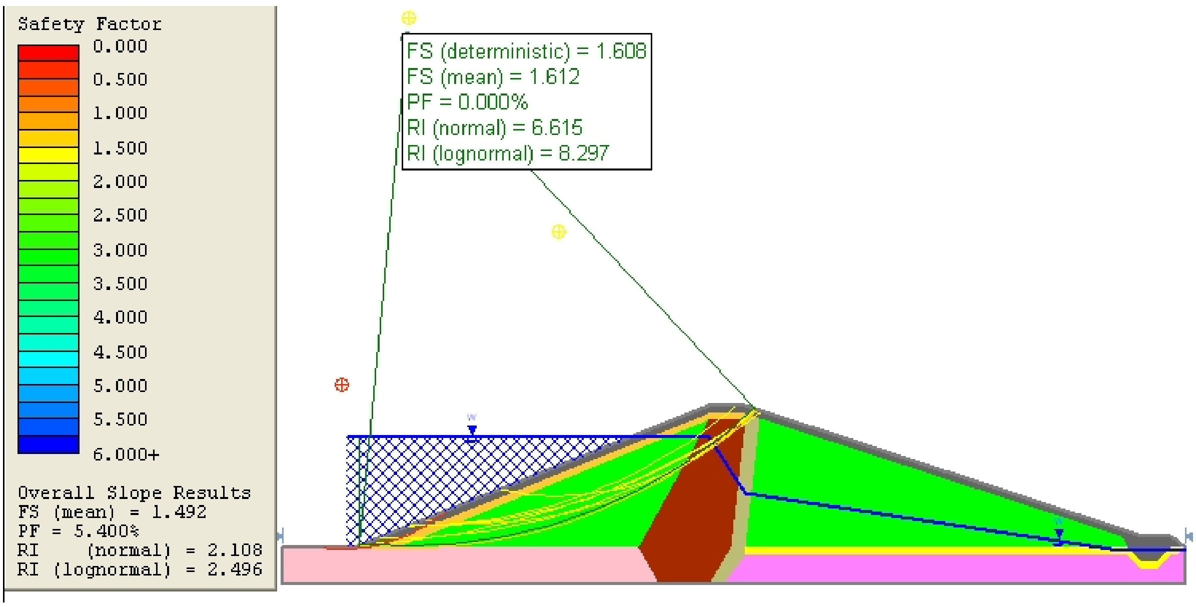

Fig.4. Cross section of Aydoghmoosh earth dam by the programs Slide

Slope stability analysis of Aydoghmoosh earth dam by Finite Elements Method (FEM))[4,6]

Finite Element Analysis was performed by the program Plaxis. In this program, the parameters C and tgΦ are decreased gradually and the safety factor is calculated by the eq.1.

$$F = \frac{C}{C_r} = \frac{tg\emptyset}{tg\emptyset_r}. \quad (1)$$

Where C and tgΦ are the real parameters as mentioned in fig.2, and Cr and tgΦr are decreased parameters.

The cross section of Aydoghmoosh earth dam as prepared by the programs Plaxis is also shown in fig.5.The overall displacement of the cross section and critical failure surface are presented in fig.6 and fig.7.

A safety factors of 1.596 was obtained with this program.

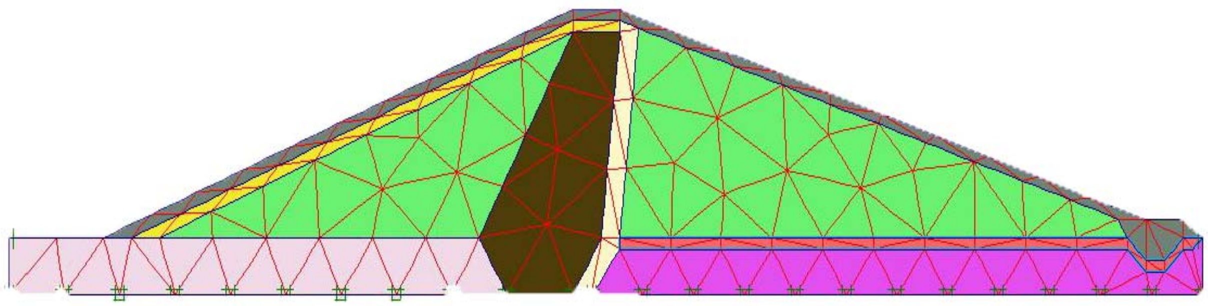

Fig.5. Cross section and mesh generation of Aydoghmoosh earth dam by the program Plaxis

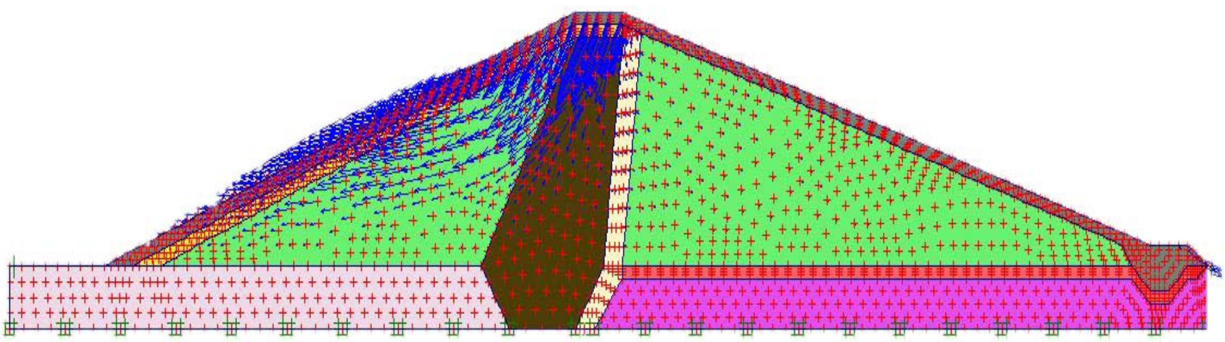

Fig.6. Overall displacement of Aydoghmoosh earth dam by the program Plaxis

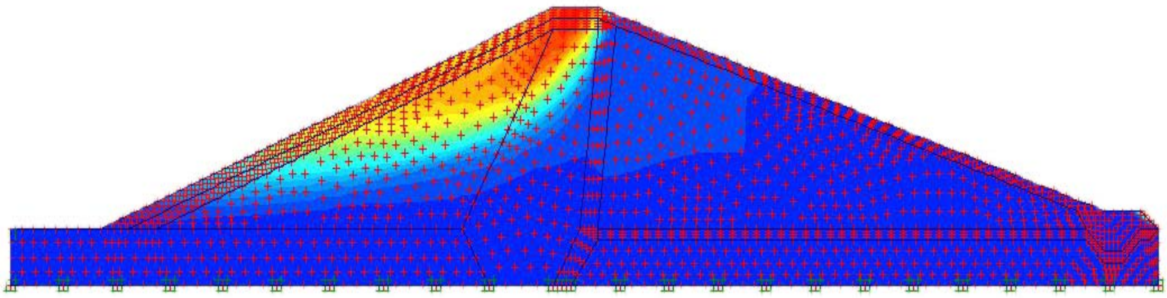

Fig.7. Critical failure surface of Aydoghmoosh earth dam by the program Plaxis

Slope stability analysis of Aydoghmoosh earth dam by Finite Difference Method (FDM) [7,8]

Finite Difference Analysis was performed by the program Flac/Slope. Flac/Slope is a small version of Flac.

The cross section of Aydoghmoosh earth dam as prepared by the programs Flac/Slope is shown in fig.8 as well. Also the mesh generation and final safety factor of Aydoghmoosh earth dam by the program Flac/Slope are presented in fig.9.

A safety factors of 1.79 was obtained with this program.

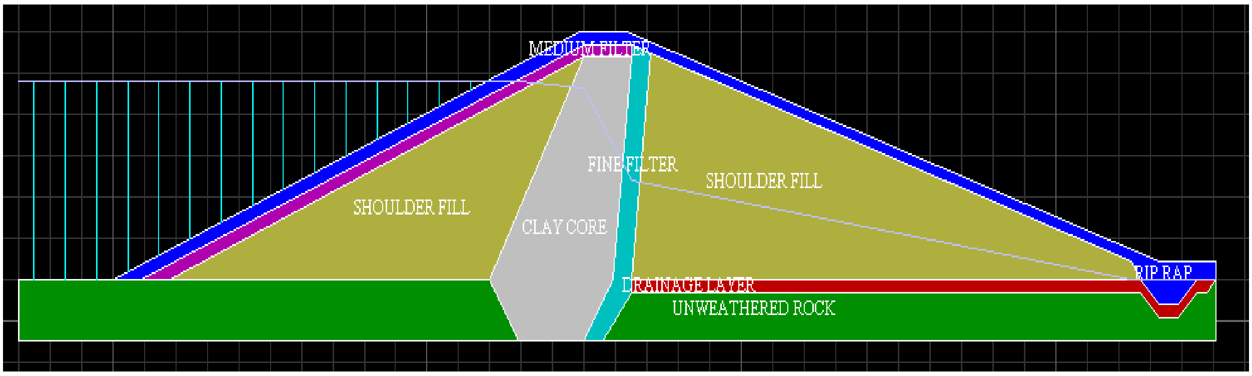

Fig.8. Cross section of Aydoghmoosh earth dam by the programs Flac/Slope

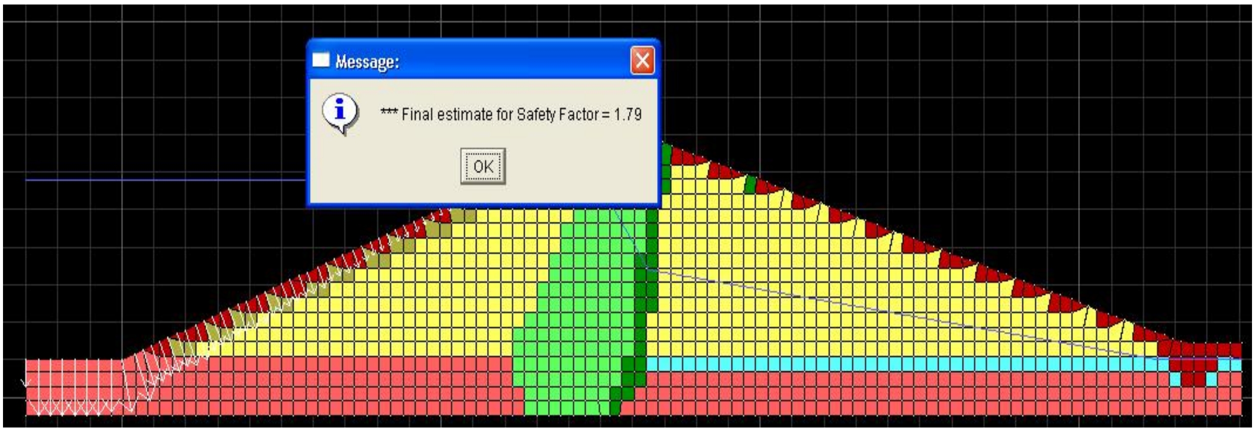

Fig.9. Mesh generation and final safety factor of Aydoghmoosh earth dam by the program Flac/Slope

Comparison of the results of slope stability analysis by different methods

The safety factor, obtained by various methods of LEM, FEM and FDM are presented together in fig 10.

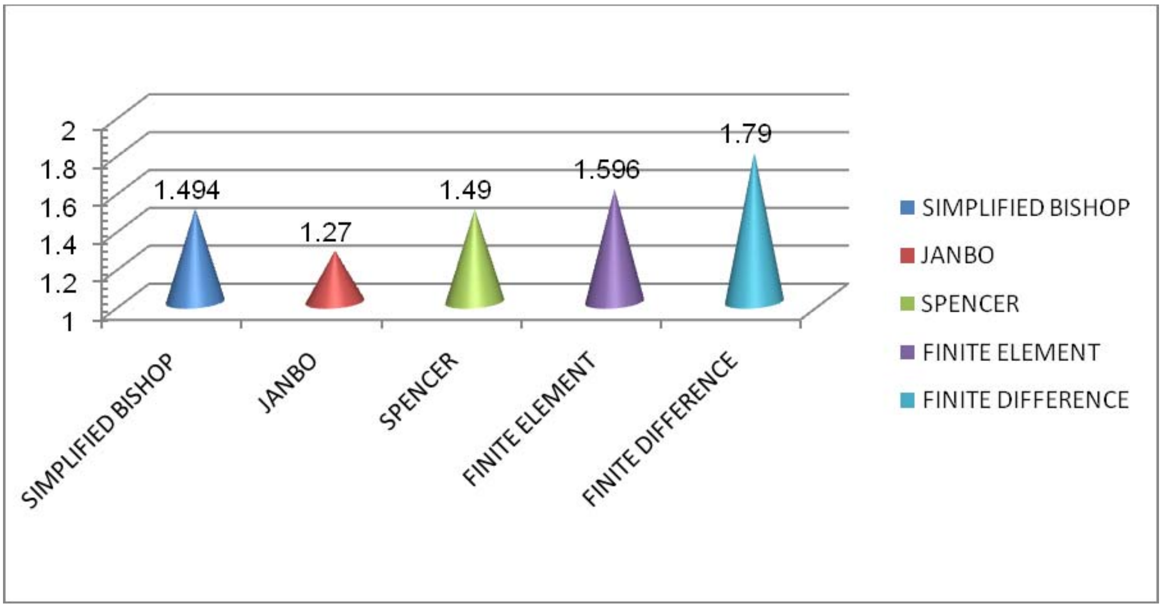

Fig.10. Comparison of the results of slope stability analysis methods

Safety factor obtained by Simplified Bishop Method and FEM are 1.494 and 1.596 respectly. The results of LEM and FEM are almost equal. Wright (1969) and Wright, Kulhway, Duncan (1973) have also riched to similar results.

Comparing the results of FEM and FDM, the safety factor obtained by FDM is 1.79 and almost 12 percent higher than FEM method.

The major differences between two program is that in FEM the parameter of elasticity modulus interfers in calculation of safety factor but in FDM this parameter wouldn't considered.

Effect of elasticity modulus on the stability safety factor

To study the effect of soil elasticity modulus on the stability safety factor, a series of analysis were performed by the program plaxis in which all the parameters exept elasticity modulus were kept constant as mentioned in table 1. Only the elasticity modulus of all layers of the dam materials were changed. In a first analysis the elasticity modulus were divided by two, and in other analysis they were multipled by two, five and ten. The obtained stability safety factor of these analysis and the rate of elasticity modulus change toward the initial state are presented in table 2. and fig.11. As seen, the safety factor increases gradually with the elasticity modulus. This increase is more important in the first three cases in this analysis, where the values of elasticity modulus is expected to be more real. This means that an appropriate determination of elasticity modulus of soil has a significant role on determination of stability safety factor.

Table 2. Sensivity analysis of elastic modulus on stability safety factor

Rate of Modulus of Elasticity change toward the initial state	Safety Factor
Half of the initial state	1.454
Initial state	1.596
Twice of the initial state	1.674
5 times of the initial state	1.881

10 times of the initial state	2.133
15 times of the initial state	2.448
20 times of the initial state	2.984

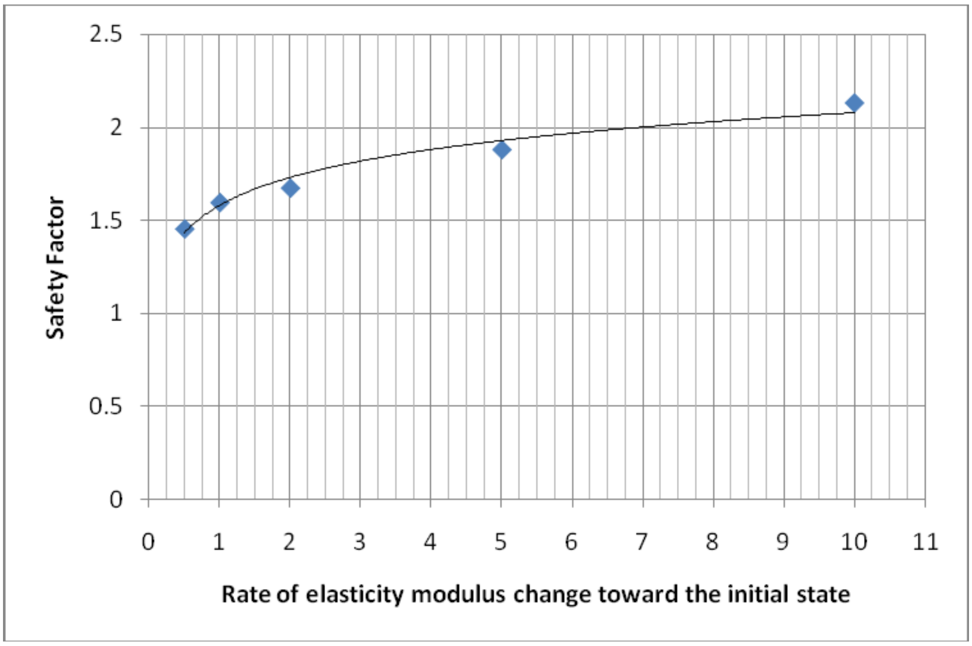

Fig. 11. Sensivity analysis of elastic modulus on stability safety factor

Summary

1- Although the Simplified Bishop Method, is simple, it is already an exact method, and the equation solving is done by trial and error method, but replies very quick and in all cases the equation is convergent. Simplified Bishop Method is considered as a simple and almost exact method in short dam designing.
2- Janbu Method is one of the most exact methods among the LEM. It is also solved by trial and error method and in most cases it is convergent and leads to the answer.
3- FEM is an exact method that relates the stresses and strains where both elastic and plastic characteristics of the earth are mentioned.
4- The results of LEM and FEM are almost equal. Weright (1969) and Wright, Kulhway, Duncan (1973) have also riched to the same results.
5- The safety factor obtained by FDM is almost 12 percent higher than FEM method. The major differences between two program is that in FEM, the program considers the elasticity modulus in calculations. Increasing the soil elasticity modulus conclude increasing of safety factor.
6- To study the effect of soil elasticity modulus on the stability safety factor, a series of analysis were performed by the FEM program in which all the parameters exept elasticity modulus were kept constant. As seen, the safety factor increases gradually with the elasticity modulus. This means that an appropriate determination of elasticity modulus of soil has a significant role on determination of stability safety factor.

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