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# TWO DIMENSIONAL MODELING AND STABILITY ANALYSIS OF SLOPES OVERLAYING TO SHAHID RAGAEE POWER PLANT

**Mohammad Sadegh, ASADI[1], Kamran. GOSHTASBI [2] , Kazem. NAJM[3]**

## ABSTRACT

One of the most important issues in the field of geomechanics is slope stability analysis. In this paper, the stability of slopes overlaying the site selected for Shahid Rajaee dam power plant was analyzed. The location of the power plant site is at the toe of two potentially unstable steep slopes. Hence, design of safe and stable slopes in this area is essential. Geomechanical properties of the slope rock mass were determined using the Graphical Back Analysis Method, Field and laboratory test. Slope stability analysis was then carried out using the two dimensional Flac code. The slopes were modeled in dry, natural water level and saturated conditions. Numerical results were verified with existing field conditions and also the Slide software, which is based on the limit equilibrium method. The results indicated that the slope is stable in static, but unstable in saturated conditions. It was also revealed that the slope is more unstable in dynamic state with earthquake horizontal acceleration ($A_x = 0.26$ g) for both dry and saturated conditions. Finally, the slope stability analysis was repeated for suggested stabilized conditions imposed on the slopes.

Keywords: Slope, Stability analysis, Numerical method.

## INTRODUCTION

There are different techniques for slope stability analysis, namely, numerical, limit equilibrium and empirical methods (Pande J.N, 1990 & Adhilary D.S et al., 1996)

In recent years, numerical methods are used in greater extent. There are various numerical methods based on continuum and discontinuous theories (Hoek & Brady, 1981 & Adhilary D.S et al., 1996), using mainly finite element, finite difference and distinct element methods.

In this study, Flac code using finite difference method and SLIDE code with the limit equilibrium method was utilized to analyze the stability of the two main unstable slopes overlaying Shahid Rajaee dam power plant site.

1- Eng. M. S Asadi, MSc in Mine Engineering (Extraction), Islamic Azad University, Research & Science Branch, Tehran, Iran, Email: Sadegasadi@yahoo.com
2- Dr. K Goshtasbi (Asst. Prof.), Faculty of Engineering, Tarbiat Modarres University, Tehran, Iran, Email: Goshtasb@modares.ac.ir
3- Dr. K Najm (Asst. Prof.), Chief Executive & Managing Director, Bistun Rock Mechanics Services co., Tehran, Iran. Email: Director@Brmsiran.com

## SHAHID RAJAEE DAM POWER PLANT

The Rajaee concrete double arch dam having a height of 127 m, 30 km south of Sari town, in Mazandaran province is constructed on the Tajan River (Asadi M.S, 2006 & ISRWO, 1995). The power plant is to be constructed at a distance of about 200 m at the left downstream bank of dam. Figure 1 shows the platform of power plant and a view of slope that overlies the site. The two slopes overlaying the power plant location have been potentially unstable due to presence of surface and underground water flow and low strength materials. Hence, this could be a would-be threat to the safety of the power plant. These slopes have suffered three landslides during and after construction stage. The slopes mostly consist of rock and soil materials as shown in table 1.

**Geo-mechanical parameters**

Geomechanical properties of the slope material were determined using Graphical Back Analysis Methods and Field and laboratory tests, in accordance to ISRM suggested methods (ISRM, 1981) and ASTM (ASTM, 1986) standards. Physical and mechanical properties of the slope material were determined for both dry and saturate states, as shown in table 1.

According to observation from boreholes and exploration sinkholes in the upper and middle parts of the slope, permanent levels of water exist at the depths from 1 m to 3 m. Hence, the slope is analyzed in the both dry and saturated states

## NUMERICAL ANALYSIS

There are various numerical methods and programs available, each of which has its own valuable application in geomechanics. The slope of Shahid Rajaee dam power plant was analyzed by FLAC, using finite difference method. Flac (Fast lagrangian analysis of continua) software can simulate elastic and elasto-plastic behavior of soil and rock structures, for the selected slopes (Pande J.N, 1990). The Flac software can model soil & rock structures (Itasca consulting group, 2002). It also has capacity to model large strain conditions. Flac can also simulate static and dynamic loads such as earthquake.

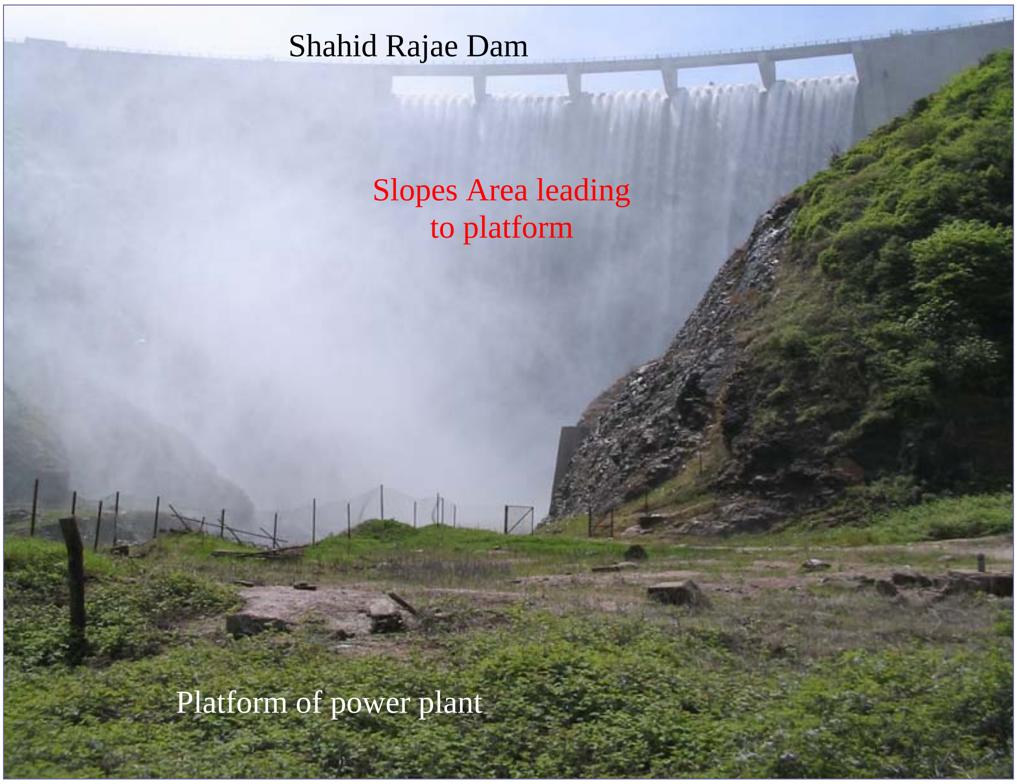


**Figure 1. Shahid Rajaee dam & platform of power plant**

**Table 1. Geomechanical properties of slope material**

| Properties \ Materials | | Dry Density (kg/m$^3$) | Saturate Density (kg/m$^3$) | Dry State | | Saturate State | |
|---|---|---|---|---|---|---|---|
| | | | | Cohesion (kg/cm$^2$) | Friction Angle | Cohesion (kg/cm$^2$) | Friction Angle |
| 1 | AL2: Pebble, Alluvium & Cement Alluvium | 1650 | 1850 | 0.0 | 24° | 0.0 | 24° |
| 2 | D: Fine Grained Soil & Sandy clay | 1750 | 1800 | 0.25 | 22° | 0.4 | 15° |
| 3 | D1: Coarse Grained Soil & Gravel | 1800 | 1900 | 0.2 | 28° | 0.2 | 28° |
| 4 | M(1,2): Marl Soil | 1850 | 2000 | 0.5 | 17° | 0.2 | 12° |
| 5 | M(gyp): Weathered Marl | 2000 | 2200 | 1.2 | 25° | 1.5 | 17° |
| 6 | Lst+m: Intact Marl | 2200 | 2400 | 1.5 | 28° | 2.0 | 30° |

## STABILITY ANALYSIS OF SLOPE – SECTION C-C'

Figure 2 shows topography map of Shahid Rajaee dam area, where sections C-C', C-C" and location of power plant are shown. The stability of the slope along Section C-C' was analyzed utilizing numerical and limit equilibrium methods, carried out in both static and dynamic states.

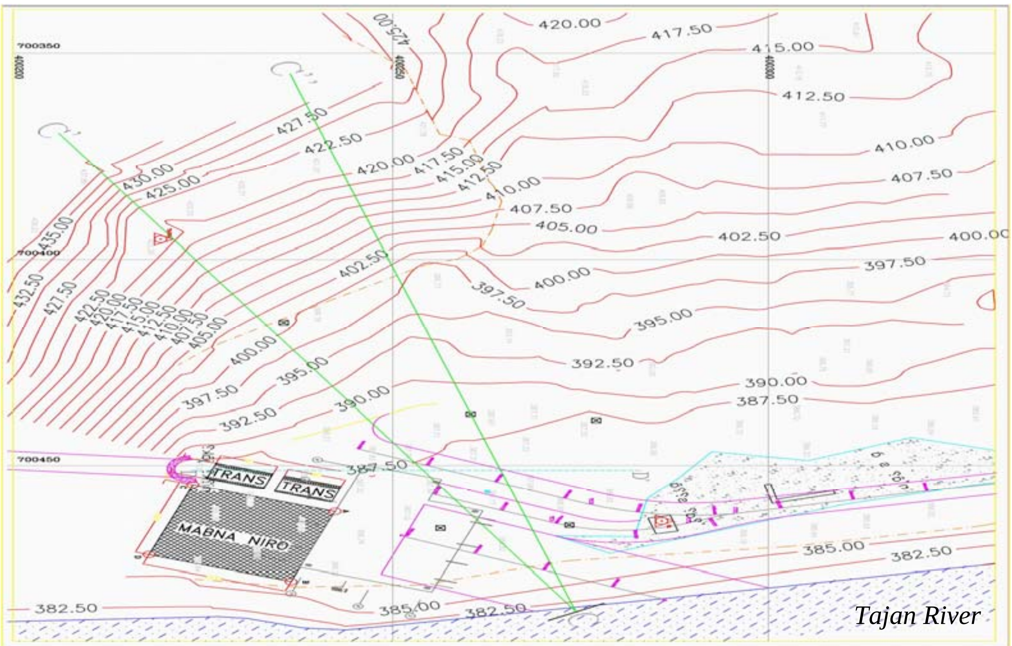


**Figure 2. Topography map of Rajaee area, C-C' and C-C" sections and The location of power plant**

**Numerical static analysis**

The Section C-C' which is directly overlaying the site selected for power plant is currently unstable. Tension cracks are observed at the top portion of the slope near the entrance to tunnel G4 and along its upper wall. The existence of such tension cracks approves the occurrence of shear failure in the slope body, which makes the slope potentially unstable.

Figure 3 shows the geometry of and geology of the slope along section C-C', which is modeled by FLAC. The geomechanical properties utilized in numerical models were those represented in table 1.

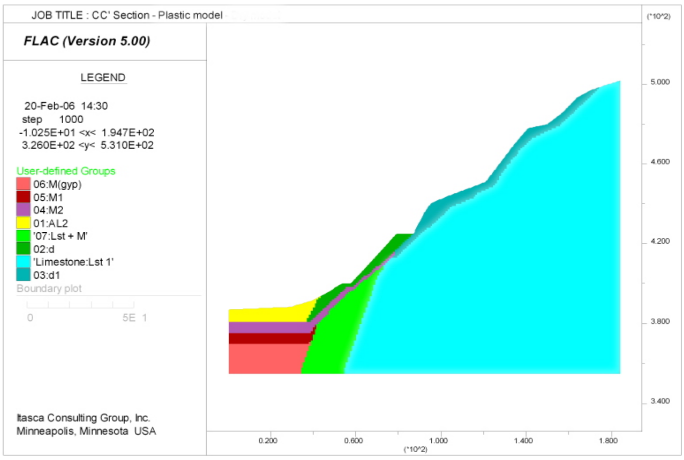


**Figure 3. The geometry of section C-C' and the material layers modeled in Flac code**

The analysis was performed for the following cases: (I) - The saturated existing slope, (II) - the saturated slope with the excavated power plant site, and (III) - the modified slope at saturated state. The above cases were then modeled and analyzed utilizing the Flac 2D code. Figures 4 - 6 show the evaluated safety factor of the above three cases, respectively.

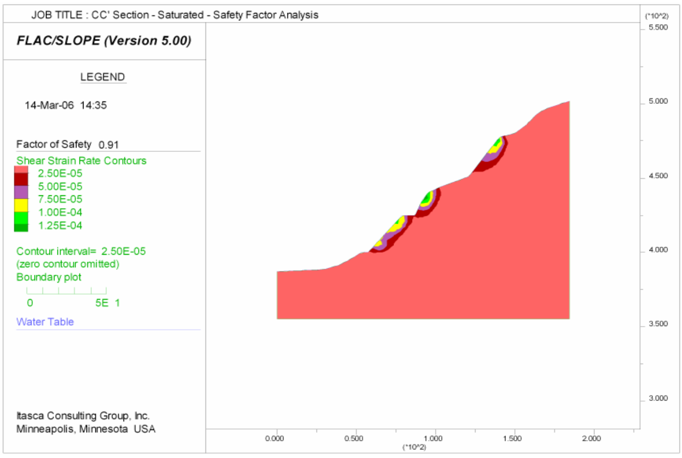


**Figure 4. Shear strain rate for saturate state, [SF=0.91]**

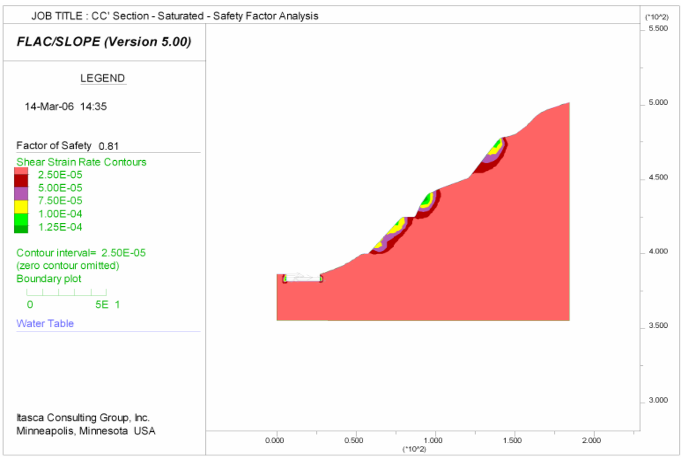


**Figure 5. Shear strain rate for saturated state with excavated base of power plant, [SF=0.81]**

As shown in figure 4, the safety factor of the slope is evaluated to be 0.91, which indicates that the slope is unstable. This instability is much likely to worsen during rainfalls where the soil layers will be saturated. Figure 5 shows the safety factor of the slope with the excavated base of the power plant to be 0.81. By comparing figures 4 and 5, it is observed that the excavation of base of the power plant has little effect on the instability of the slope. However, there is small reduction of safety factor from 0.91 to 0.81 which can be due to minor changes of stress concentration in foundation layers and areas around the power plant. It should also be noted that the walls around the power plant have the potentials to slide due to nature of materials.

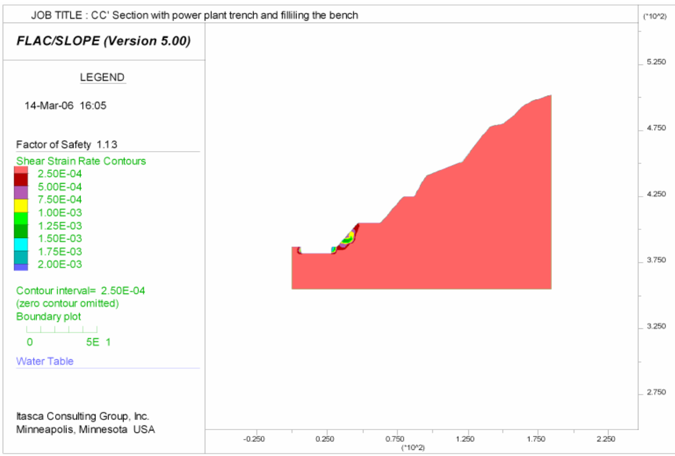


**Figure 6. Shear strain rate for saturated state with modified slope's toe, [SF=1.13]**

In order to stabilize the slope, the toe was reinforced by using materials similar to those of the led to the situation shown in figure 6, with slope safety factor upgraded to 1.13. Due to high steepness of the reinforced wall, possibilities of local slides exist. In order to avoid these local slides, gabion wall with wire entanglement and in special circumstances, reinforced concrete can be used to stabilize the wall and floor of foundation of the power plant.

**Numerical Dynamic Analysis**

The dynamic loads have significant effect on the stability of these slopes. Hence, the dynamic analysis of the slope along Section C-C' was conducted. The dam is about 10 km from the great North Alborz fault, which is regarded as an active fault in Iran. According to deterministic and probabilistic seismic hazard analysis, the seismic design levels and their related horizontal and vertical accelerations were determined, and are shown in table 2.

The dynamic analysis of the slope was then conducted, with the input data given in table 2. As it was previously mentioned, the slope is found to be unstable in dynamic state in both dry and saturated conditions.

**Table 2. Possible amounts of vertical and horizontal acceleration In the area of Rajaee dam**

| Planning Level | Vertical Acceleration (g) | Horizontal Acceleration (g) |
|---|---|---|
| ODE[4] | 0.17 | 0.26 |
| MDE[5] | 0.30 | 0.43 |
| MCE[6] | 0.46 | 0.55 |

[4] Operating design earthquake
[5] Maximum design earthquake
[6] Maximum credible earthquake

Hence, the dynamic models were analyzed in saturated state, in order to investigate the most critical and probable landslides in the slope due to seismic loads. Figures 7 - 10 and table 3 show the results gained from the dynamic numerical analyses and their comparison to static state results.

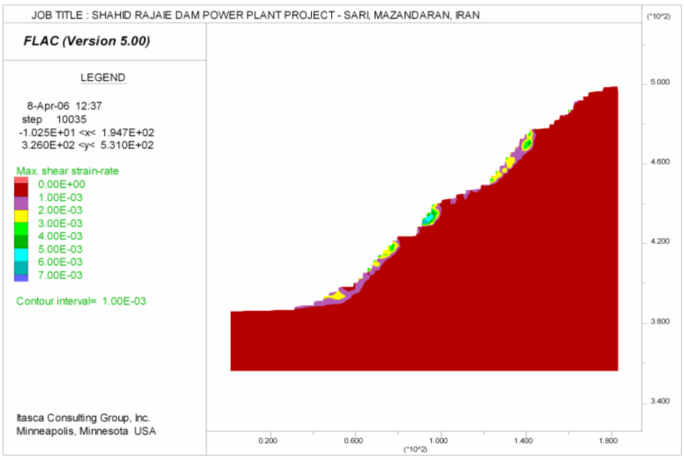


**Figure 7. Shear strain rate - static analysis**

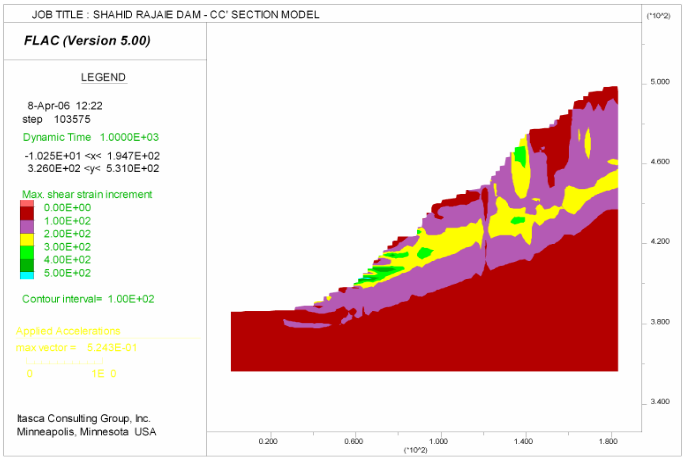


**Figure 8. Shear strain rate - dynamic analysis**

By comparing the results obtained from numerical analyses, it is undoubtedly indicated that the slope is more unstable in dynamic condition than in static state.

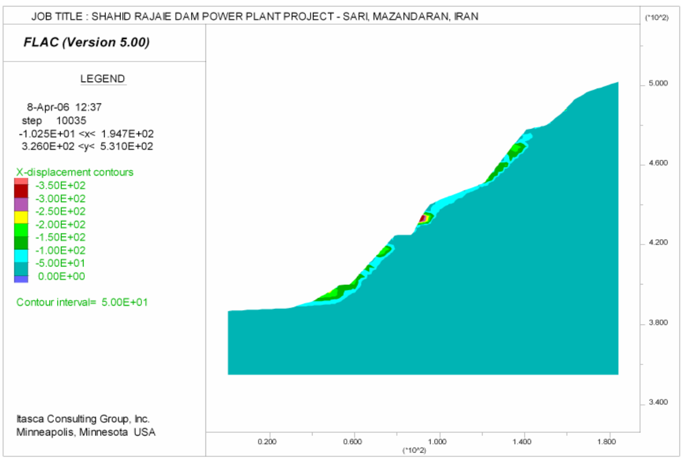


**Figure 9. Horizontal displacement curves - static analysis**

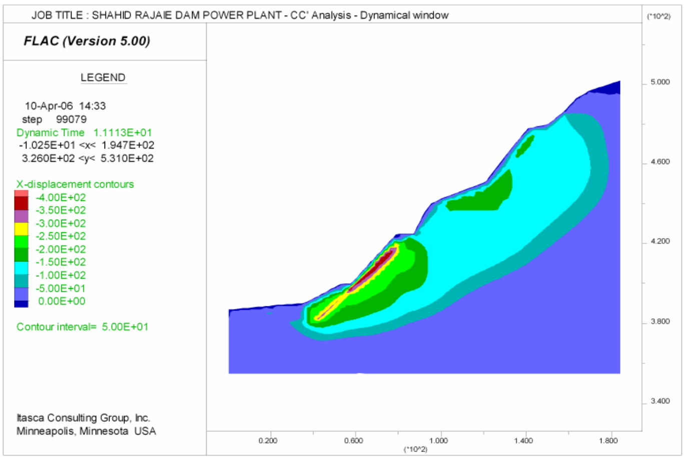


**Figure 10. Horizontal displacement curves - dynamic analysis**

**Table 3. Comparison between dynamic and static analyses**

| Parameter / Analysis | Horizontal Displacement (mm) | Vertical Displacement (mm) | Safety Factor | Max. Shear Strain rate |
|---|---|---|---|---|
| Static | 2.5 E +1.0 | 2.5 E +1.0 | 0.91 | 1.0 E -03 |
| Dynamic | 5.0 E +1.0 | 5.0 E +1.0 | 0.61 | 1.0 E +02 |

The safety factors of the slope in saturated state for static and dynamic condition are evaluated as 0.91 and 0.61, respectively.

If an earthquake having a horizontal acceleration of 0.26 g occurs in the area, a landslide will definitely happen in the main slope.

## LIMIT EQUILIBRIUM ANALYSIS

The main slope is then analyzed using the SLIDE software which is based on limit equilibrium method. The analyses were conducted for dry, natural water level and saturated conditions.

The safety factors in the critical parts of the slope were then calculated, based on theories of Bishop simplified, Jambu simplified, Jambu corrected and Spencer theories (Hoek & Brady, 1981).

The results are shown in table 4, which confirms the results gained from numerical analysis. Minor differences in safety factors could be due to analysis methods and precision of such methods.

The results clearly show that the main slope is stable in dry condition and unstable in saturated condition.

**Table 4. Safety factors using limit equilibrium methods**

| State / Method | Saturate | Natural Water | Dry |
|---|---|---|---|
| Bishop Simplified | 0.997 | 1.238 | 1.444 |
| Jambu Simplified | 0.957 | 1.206 | 1.416 |
| Jambu Corrected | 0.992 | 1.253 | 1.464 |
| Spencer | 0.993 | 1.242 | 1.449 |

## CONCLUSION

From the results obtained in this research study, it can be concluded that:

1- The slope is stable in dry state and unstable in saturated state.
2- In order to stabilize the slope, the slope's toe should be reinforced, with the safety factor of the slope upgraded from 0.81 to 1.13.
3- The analyses in dynamic condition show that the slope is more unstable in dynamic condition. The safety factors of the main slope in static and dynamic condition at saturated state were found to be 0.91 and 0.61, respectively.
4- The limit equilibrium results also confirm the findings of numerical analyses in these studies.

## REFERENCES


Adhilary D.S, Dyskin, A.V, Jewell, J.J, “Numerical Modeling of the Flexural Deformation of Foliated Rock Slope”. Int.J.Rock Mech. Min Sci & Geomech. ABBSTR, PP 595-606, 1996

American Society for Testing and Materials, ASTM book of standards, Sec. 4, Vol. 04.08, Philadelphia, Paris, 1986

Asadi M.S, “Stability Analysis of Slopes Overlaying to Rajaee Dam Power Plant”, MSc theses in mine extraction engineering, Azad university of Tehran, research & science branch, 2006 (in Farsi)

Cho S.E, Lee S.R, “Instability of unsaturated soil slopes due to infiltration”, Department of Civil Engineering, South Korea Advanced Institute of Science and Technology, Taejon 305-701, 2000

Flac Manual, “User’s Guide Flac 5.00”, Itasca Consulting Group, Inc, 2002

Hoek and Brady, Third edition of “Rock slope engineering”, Institute of Mining and Metallurgy, London, 1981

Iran Sari regional water Organization (ISRWO), 2$^{nd}$ Report of “Rajaee Dam Engineering Geology”, Ref No: 186610-1300-2219, 1995 (in Farsi)

International Society for Rock Mechanics, ISRM book of standard, Portugal, 1981

Pande J.N, “Numerical Methods in Rock Mechanics”, John. Wiley and Sons, 1990