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# Seepage Analysis of Rock-Fill Dam Subjected to Water Level Fluctuation: A case study on Gotvand-Olya Dam

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**Abstract:** The Gotvand-Olya Dam is a rock-fill dam, located at Khuzestan province in southwest of Iran. Since the dam is subjected to the daily water level fluctuation, such as rapid drawdown and refill, thus induce a structural impact on the behavior of dam body, it draws many soil engineering concerns. In this paper, seepage analysis of the rock-fill dam was primarily conducted to evaluate the dam safety against the leakage through the dam body. Traditionally, steady-state analysis was employed to investigate the seepage in the dam body, summing that water level is fixed at two cases: high and low water levels. Consequently, it was not able to properly reflect the time-dependent characteristics of seepage phenomena. In this study, seepage analysis was numerically performed using 2-D FEM transient analysis. As a particular boundary condition for an analysis, the water level fluctuation was incorporated to simulate the daily changes. As a result, various seepage phenomena were quantified such as hydraulic gradient, seepage vector and pore water pressure distribution at the corresponding time of interest as the water level rises and recedes. At steady state analysis, the seepage flux at high water level in downstream area was predicted to be 78 l/s. In additions, the seepage flux measured and estimated were both acceptable considering design criteria. The result of this study proves that there is no sign of hazardous sources contributing to the possibility of piping, internal erosion and excess leakage through the dam body.

**Key words:** Seepage · Hydraulic structures · Net flow · Finite elements · Gotvand-Olya Dam

## INTRODUCTION

In eyes of engineers, dams are known as alive structures. Because of changes of geology and other criteria of dams; these structures may also changes. For these reasons, dams should certainly be designed and built with high assurance for a long duration of time. Awareness of such changes is related to dams and the specified surrounding environment. Special devices are required to predict dam's behavior. Water through reservoir may possibly move behind and depth of dams [1]. Seepage flow of water through porous media depends on the soil media, type of flow, properties of liquid and hydraulic gradient. Seepage piping account for approximately 50% of all earth dam failures [2].Water running from dam's reservoir, especially from earth dams has important role on dam stability [3]. Generally, several methods for decreasing water leakage through dams have been used [4]. Specially, type of construction material for dam foundation, borrowing materials, type of design, geometrical shape and empirical limitation has influenced on dam storage capacity [5-7]. Water leakage on earth dams and it's method of seepage control is the first step of designing embankment dams [8, 9]. Science and technologies related to basic seepage rules have given necessary information to scientists to control and overcome any encountered problems [10-12]. Recently many scientists studied and analyzed the effective parameters on seepage process and they were able to solve many cases by designing issues [13, 14]. Kamanbedast *et al*. [4, 5] have investigated on earth dam; they have demonstrated powerful software which was able to determine the seepage [4, 15]. However, each dam has its own configuration and descriptive design. Special attention is required to know detail information about the seepage.

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Fig. 1: Landscape of top crest of Gotvand-Olya Dam

In this research, practical software has been applied to predict seepage. A successful attempt was made through numerical design calculations. The desired methods of control and monitoring techniques of leakage such as trench depth, thickness of clay blanket, some physical and geometrical characteristics of dams; also infiltration, upstream and down steam protections have been applied and extensively investigated [3, 6, 8, 14- 18]. Baziar *et al*. [19] carried out some numerical and experimental tests for Meyjaran dam in Iran with the height of 60 *m*. They inferred that the asphalt concrete core behaves safely, even under very severe earthquake; also it can satisfy the seismic design criteria under DBL, MDL and MCL levels of earthquake loadings [19]. The Gouhou Dam was one of many dam failures related to seepage during reservoir filling. According to the available statistics [20-22], other than overtopping, internal erosion and piping caused by seepage are the primary causes of failures and incidents in embankment dams. In 1976, Teton Dam in the United States failed due to erosion of the core material near the abutment during initial reservoir filling [23]. In 1961, Panshet Dam in India failed due to piping when the first phase was nearcompletion [24]. Abutment seepage was also the cause of some additional incidents at earth or rock fill dams, such as Clear Branch Dam, East Branch Dam and Navajo Dam [20, 23]. Feizi-Khankandi *et al*. [25] performed a 2*D* nonlinear analysis on a 125*m* typical asphaltic concrete corerock fill dam. The results of the study showed that appropriate response of the dam during and after an earthquake. In this study, Gotvand-Olya Dam as prototype was used. The dam is located at Khuzestan province in southwest of Iran (Figure 1).

**Aim and Necessary Method of Operation:** This research is necessary to be conducted, because of dam structure (Gotvand-Olya Dam is the highest dams in Iran) and it has significant role in electricity generation and water reservoir management for the agricultural use. First of all several methods of seepage control calculations were carried out; then, seepage for Gotvand-Olya Dam was mathematically analyzed. Finally based on the best outcome the best method has subsequently been driven.

## MATERIALS AND METHODS

**Dams Geographical Location:** Earth dam of Gotvand-Olya is constructed across Karun River at a distance of 25 Km at the north of Shoshtar town and close to Gotvand town. Gotvand-Olya Dam with capacity of water maintaining and is the biggest dams in Iran. Basic aim of these dams is to provide the demanded water flow rate of greater for Khuzestan land. In addition, with annual rate of about 1000 mega Watt Hours electrical power was generated. This structure was also used for flood control of Karoon River. Gotvand-Olya Dam is an earth type with centre clay core and elevation is about 244 meters. Crest length is equal to 760 meters. Crest elevation is 246 meters and bottom of foundation at minimum level is 64.5 meters up from the free surface of sea level. Figures 2 and 3 are typical cross section and foundation of the dam. The specification of Gotvand-Olya Dam is summarized in Table 1.

**Introducing Software:** Seep/w software is one of powerful program works based on finite elements technique and it is able to simulate and analyze isometric water distribution through soil and rocks. Prefect developed formula of software make it possible to analyze very complex water seepage formula.

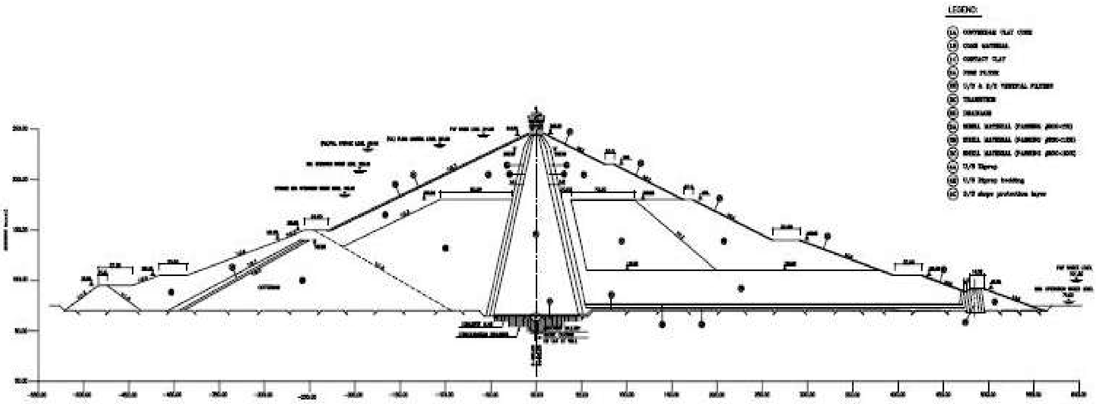

Fig. 2: Typical cross section of upper Gotvand-Olya Dam

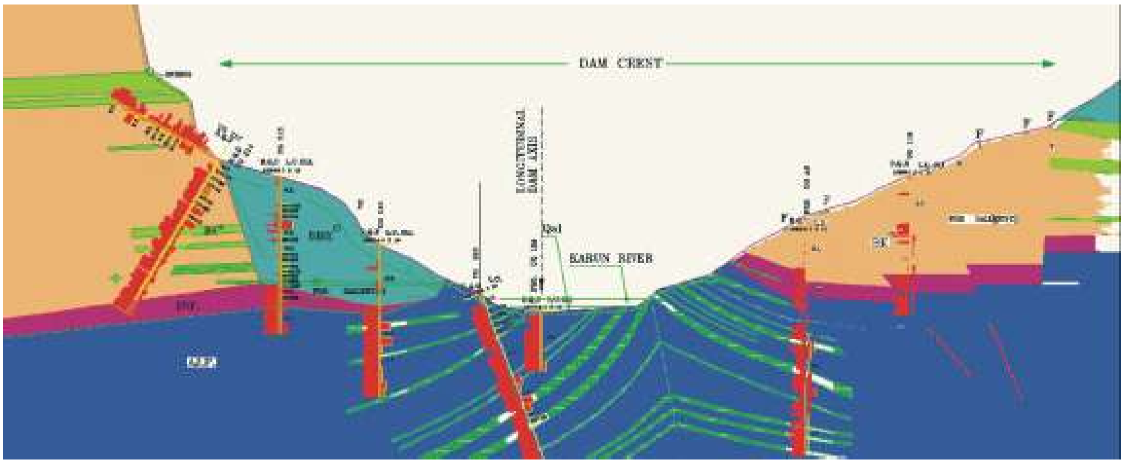


Fig. 3: Typical cross section of foundation of Gotvand-Olya Dam

Table 1: Specification of Gotvand-Olya Dam

| Type of dam: rock fill with clay core | Volume of earth fill: 30.8 MCM ( including upstream cofferdam volume) |
|---|---|
| Highest from foundation: 182 m | Volume of earth fill under dam body: 7MCM |
| Crest length: 760 m | Reservoir total volume: 5.2 MCM at PMF level and 4.5 MCM at maximum operation elevation |
| Crest width: 17 m | Reservoir area: 96.58 $Km^2$ at 234 m above sea level |
| Crest elevation: 246 m above sea level | Reservoir length: 90 Km at 234 m above sea level |

**Method of Analysis:** For simulation and investigation of seepage through dams (seep/w) software was used. Continuity phase of liquid, Darcy equation behavior of seep zone and UN isotropic are the assumption utilized in these equations. In a porous environment analysis, with different boundary conditions effectively been used (Figure 2). Gotvand-Olya Dam is made up in mesh within the assigned compartments is shown in Figure 3. In the computational program, two dimensional analyses were successfully carried out with the assumption of uniform seepage at critical section [4, 5, 13]. Figure 4 is Mesh of Gotvand-Olya Dam.

**Producing Seepage Model:** Analysis of the schematic cross sectional earth dam of Gotvand-Olya showed that five zones are distinctly observed.

- Zone 1 is clay core (impervious core)
- Zone 2 is upstream rock fill.
- Zone 3 is filter
- Zone 4 is vertical drain

Table 2 summarized the hydraulic gradient coefficients recorded by the flow rates at different layers of the dam.

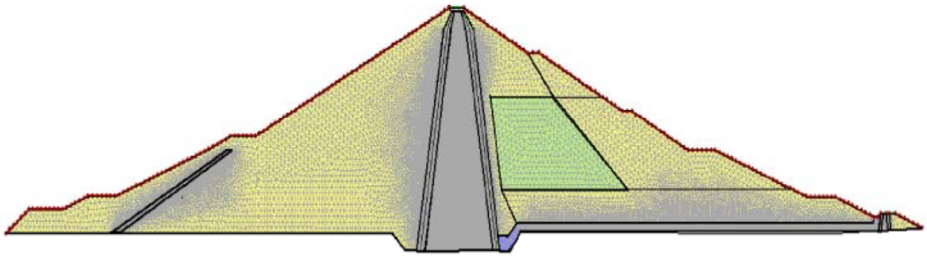

Fig. 4: Mesh of Gotvand-Olya Dam

Table 2: Hydraulic gradient coefficients by the flow rates at different layers of the dam

| No | Type of material | K hydraulic Gradient Coefficients m/s |
|---|---|---|
| 1 | Core clay | 1e-9 |
| 2 | Filter | 1e-6 |
| 3 | Rock fill dam | 1e-5 |
| 4 | Drain | 1e-2 |

Table 3: Discharge rate with respect to dam elevations water depth

| Water level (m) | Discharge (l/s) | Measured discharge(l/s) |
|---|---|---|
| 135 | 14 | 13 |
| 150 | 18 | 17 |
| 185 | 22 | 21 |
| 209 | Water still did not arrive to this range | 36.5 |
| 230 | Water still did not arrive to this range | 46.4 |
| 234 | Water still did not arrive to this range | 64.5 |
| 244 | Water still did not arrive to this range | 78 |

## RESULTS

Use of the obtained data and specification of different layers of the dam and seepage analysis (with the aid of software) some meaningful tables and figures are driven. The demonstrated sectional analysis is illustrated as follows:

Table 3 shows the calculated and measured seepage discharge flow rates with respect to dam elevations of reservoir water depth. The seepage rates have been gradually estimated for the different elevation of reservoir flow rates were very close to actual values. Figure 5 shows the flow rate under earth dams at elevation of (185 m) above the free surface. In Figures 5 and 6 demostrate the pore-water pressure rate under earth dams at elevation of (209 m) above the free surface. In addition, Figure 7 illustrate the total head rate under earth dams at elevation of (209 m) above the free surface.

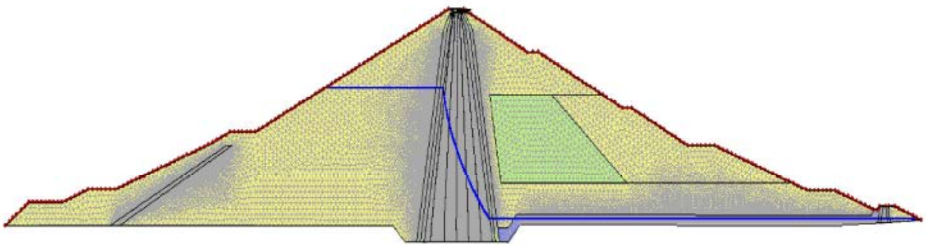

Fig. 5: Flow rate under earth dams at elevation of (185 m) above the free surface

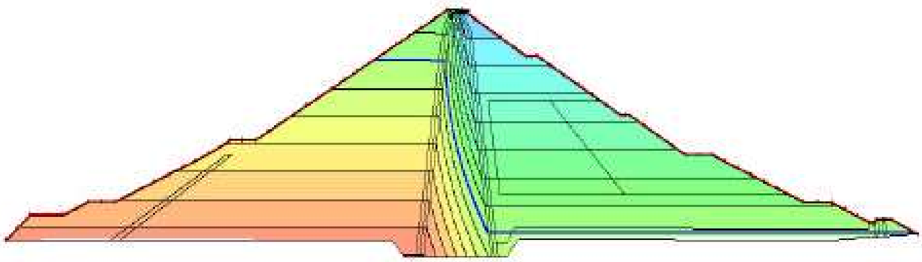

Fig. 6: The pore-water pressure rate under earth dams at elevation of (209 m) above the free surface

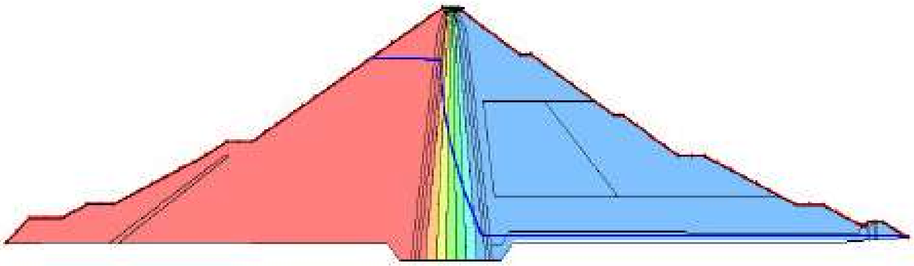

Fig. 7: Total head rate under earth dams at elevation of (209 m) above the free surface

## DISCUSSIONS AND CONCLUSIONS

- Seepage analysis was successfully carried out with the use of two dimensional models. In addition, one has to consider the restriction and limitation of the software.
- In order to have accurate analysis, it is recommended to carry out three dimensional analyses using advanced software to handle required calculations.
- In a similar dam condition (like Gotvand-Olya), it is desired to conduct control of seepage operation at the time dam constructions and dam building period and before water intake. Firstly, open trench and drain pipe are often utilized with higher efficiency. Separation walls are empirically restricted beneath core.
- Besides that, it is recommended another underground water gallery to be built at water runs beneath the core.
- For determination of seepage in earth dam, it is desired for the modeling and simulation without considering up and down streams shell and exist drain and filter and condition core, foundation saturation before cut off; because of the limited time. In that case the seepage is exactly determined.
- It was concluded that the result of seepage software, seep/w software is reliable and trustable software to model a dam.

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