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Evaluation and Seepage Analysis of Rock-Fill Dam Subjected to Water Level with Seep and Flac in Gotvand-Olya Dam

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Abstract: Building dam is very rapidly developing in Iran; then caring the technical points will help us to maintain their firmness and strength and also use it in suitable manor. One of the problems of soil dams in the world is the seepage and leaking phenomena. The problem of leaking of water and the ways of controlling the leakage in soil dams is one of the most important technical problems in designing, building, well maintaining and use of soil dams. In this analysis, hydraulic circulation in spongy environments and numeral methods of solving equation of water circulation in saturated soils was analyzed and then leakage analysis was performed using mathematical models. Finally, analyzing of applied model was conducted using Flac2d, Seep/w2d software. The soil dam of Gotvand Olya was considered as special study and the amounts of leakages in heights of 135, 150, 185, 209, 230, 234 and 244, were analyzed. Data at the height of 135,150,185 were compared. In conclusions using exact tools it was found that the obtained results of Flac2d software was more precise than Seep/w2d software.

Key words: Gravel dam · Flac2d · Gotvand Olya dam · Leakage · Seepage · Seep/w2d

INTRODUCTION

In eyes of engineers, dams are known as a live structure. 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 dams' 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 counts 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, different methods for decreasing the running water 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 water stopping factor of dams [5, 6]. Water leakage at earth dams and it's method of seepage control, is the first step of designing embankment dams [7, 8]. Science and technologies related to basic seepage rules have given necessary information to scientists to control and overcome any encountered problems [9-11]. Recently many scientists studied and analyzed the effective parameters on seepage process and they were able to solve many cases by designing issues [12, 13]. Kamanbedast *et al*. [4] have investigated on earth dam; they have demonstrated powerful software which was able to determine the seepage [4, 14]. However, each dam has its own descriptive design and configuration. Special attention is required to know detail information about the seepage. In this research, practical software has been

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applied to predict seepage. A successful attempt was made through numerical designing. 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 such as infiltration, upstream and down steam protections have been used and extensively investigated [2, 4, 6, 7, 12-18]. Baziar and Salemi [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 and it can satisfy the seismic design criteria under earthquake conditions (DBL, MDL and MCL levels) and earthquake loadings [17, 20]. The Gouhou Dam was one of many dam failures related to seepage during reservoir filling. According to the available statistics [21-23], other than overtopping, internal erosion and piping caused by seepage are the primary causes of failures and incidents in embankment dams. Teton Dam in the United States failed in 1976 due to erosion of the core material near the abutment during initial reservoir filling [24]. Panshet Dam in India failed in 1961 due to piping when the first phase was near completion [25, 26]. 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 [24]. Feizi-Khankandi *et al*. [27] performed a 2*D* nonlinear analysis on a 125*m* typical asphaltic concrete core rock fill dam. The results of the study show the appropriate response of the dam during and after an earthquake.

Aim and Necessary Method of Operation: This research is necessary to be conducted, because of dam the 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 usage. 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: In this study, Gotvand olya Dam as prototype was used. The dam is located at Khuzestan province in southwest of Iran (Figure 1). Also typical cross section and foundation of upper Gotvand-olya dam shows in Figures 2 and 3.

Fig. 1: Landscape of top crest of Gotvand_olya dam

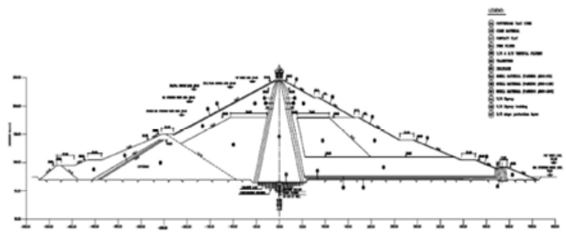

Fig 2: Typical cross section of upper Gotvand-olya dam

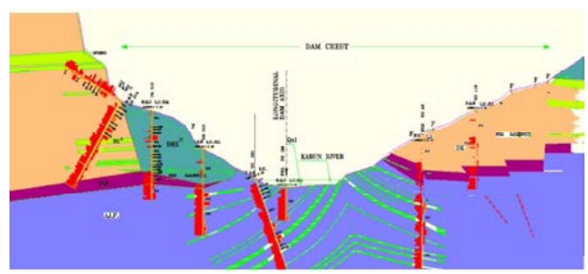

Fig. 3: Typical cross section of foundation of Gotvand-olya dam

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 of high water flow rate for Khuzestan land. In addition, the dam has to generate power with annual production rate of about 1000 Mega Watt hours electrical power. 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. Table 1 summarized specification of Gotvand-olya dam [27].

Earth dam of Gotvand olya is under construction across Karoon River at a distance of 25 Km at the north of Shoshtar town and close to Gotvand town.

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

Tabled 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.a.s.l
Crest elevation: 246 m.a.s.l	Reservoir length : 90 Km at 234 m.a.s.l

through soil and rocks. Prefect developed formula of software make it possible to analyze very complex water seepage Formula.

FLAC is a two-dimensional explicit finite difference program for engineering mechanics computation. This program simulates the behavior of structures built of soil, rock or other materials that may undergo plastic flow when their yield limits are reached. Materials are represented by elements, or zones, which form a grid that is adjusted by the user to fit the shape of the object to be modeled. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to the applied forces or boundary restraints. The material can yield and flow, the grid can deform (in large-strain mode) and move with the material that is represented. The explicit, Lagrangian calculation scheme and the mixed-discretization zoning technique used in *FLAC* ensure that plastic collapse and flow are modeled very accurately. Because no matrices are formed, large two-dimensional calculations can be made without excessive memory requirements. The drawbacks of the explicit formulation (i.e., small time step limitation and the question of required damping) are overcome to some extent by automatic inertia scaling and automatic damping that do not influence the mode of failure [28].

Though, *FLAC* was originally developed for geotechnical and mining engineers, the program offers a wide range of capabilities to solve complex problems in mechanics. Several built-in constitutive models are available that permit the simulation of highly nonlinear, irreversible response representative of geologic, or similar, materials [28].

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 the equations. It was effectively used in a porous environment analysis, with different boundary conditions (Figure 2). Gotvand olya Dam is made up in mesh within the assigned compartments is shown in Figure 4. In the computational program, two dimensional analyses were successfully carried out with the assumption of uniform seepage at critical section [4, 11].

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

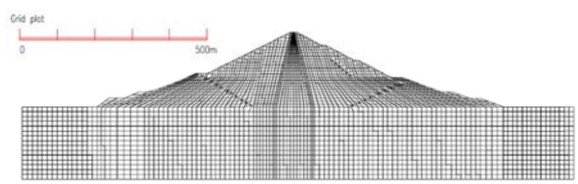

Fig. 4: Mesh of Gotvand-olya Dam

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.

RESULTS

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

Tables 3 and 4 show 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 flow rate under earth dams at elevation of (185 m) above the free surface. Also Figure 6 shows pore-water pressure and total head rate under earth dams at elevation of (209 m) above the free surface.

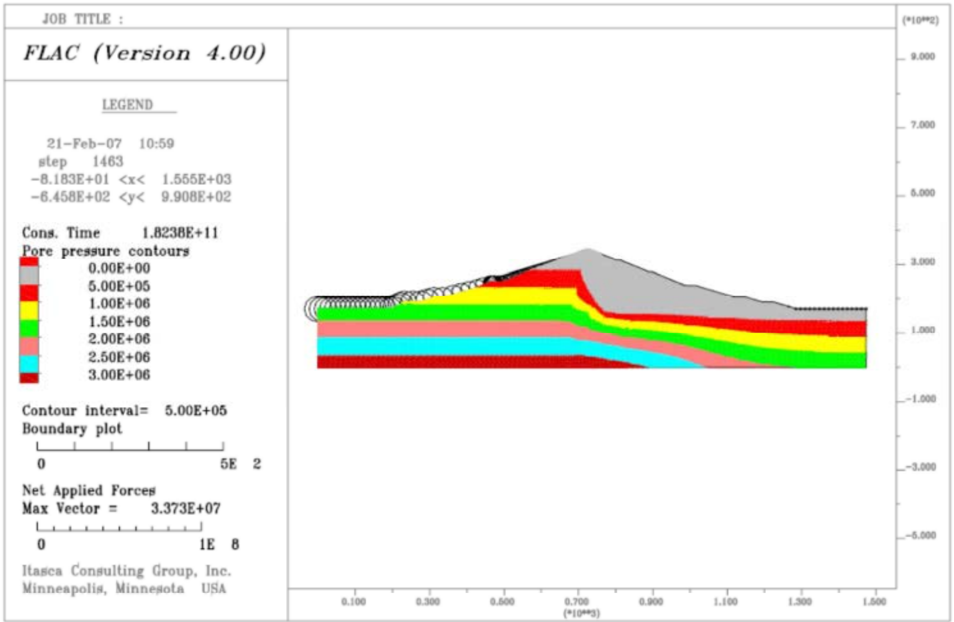

Fig. 5: Flow rate under earth dams at elevation of (185 m) above the free surface in the Flac

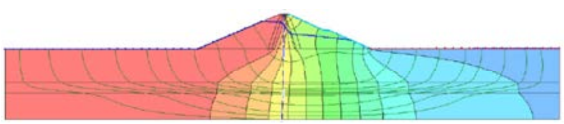

Fig. 6: Pore-water pressure rate under earth dams at elevation of (209m) above the free surface in the seep/w

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

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

Table 4: Discharge rate with respect to dam elevations water depth with Flac

Water level (m)	Discharge (l/s)	Measured discharge (l/s)
135	14	14
150	18	18
185	22	21.5
209	Water still didn't arrive to this range	37.5
230	Water still didn't arrive to this range	48
234	Water still didn't arrive to this range	66
244	Water still didn't arrive to this range	80

DISCUSSIONS

As we can observe, the amounts of accounting in Flac3d was near to real amounts and we didn't observe any danger of water washing in dam body in any balances. Regarding water deep change in dam length, the calculating amounts was near to reality only when leakage analysis is done in two or three dimensional methods. One should not forget that numeral model making of leakage in non-continual method rather than to other one; that is resulted desired output; because of using time steps of changes of water levels at the back of the dam, the leakage level and pissometric bar of each time step in the model will be exactly accounted.

General conclusion the passing leaking amount from length section on the axis was accounted and the leakage amount of these three soft wares with utmost difference of 78 liters per second in SEEP/W software and 80 liters per second are in Flac2d software and these differences are because of simplification in dam building. Tables 2 and 3, the amount of leakage in different water filling balances with application of both softwares are demonstrated.

We can observe that in distributing leakage forces in both softwares are as the same and the generated results are almost the same. The calculating amount in all three models have only theoretical values and they never can be compared with the total leakage quantities from the dam at rest points. The reasons are the topography position of dam construction, having seams, cutting of water keeping walls in some places and non-even body of dam in its length. Regarding the changes of water keeping depth in dam length, the amount of calculating leakage quantities never is close to reality only when the leakage analysis is conducted as two or three dimensional methods.

One should not forget that the numeral leakage model making in non-continual case will have a better results than continual case, because of using time steps related to level of water at the back of the water keeper, the leakage level and pissoometric bar related to each time step in mentioned model making, is exactly accounted. Referring to carrying out model making and the results of leakage analysis in Flac2d, Seep/w dams, the importance and value of using homogenous core and area making crusts for controlling the phenomenon of leakage in soil dams was firmed.

CONCLUSION

The Following Conclusions Are Drawn:

- 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 one dam.

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Persian Abstract

چکیده

با توجه به اینکه ساخت سد در کشورمان با سرعت چشمگیری در حال افزایش است لذا توجه به نکات فنی ما را به رسیدن به استفاده هر چه بهینه تر از سدها و همچنین استحکام آنها کمک می کند. یکی از معضلات موجود در سد های خاکی در دنیا ناشی از پدیده «نشت و تراوش» می باشد. مسئله تراوش آب و روش های کنترل آن در سدهای خاکی یکی از مهمترین مسائل در طراحی، ساخت، نگهداری و بهره برداری از اینگونه سدهاست. در این تجزیه و تحلیل هیدرولیکی جریان در محیط های متخلخل و روش های عددی حل معادله جریان آب در خاک های اشباع مورد بررسی قرارگرفته و سپس آنالیز تراوش با استفاده از مدل های ریاضی و در نهایت تحلیل این مدل ها توسط نرم افزارهای Seep/w وFLAC2D انجام گردید. در این پروژه سد خاکی گتوندعلیا به عنوان یک مطالعه موردی انجام گرفته و مقادیر نشت در ارتفاع های ۲۰۹،۱۸۰،۱۵۰،۱۳۵ ، ۲۳۰، ۲۳۴ و ۲۴۴ متر از ارتفاع آزاد دریا برآورد شد و در ارتفاع ۱۳۵، ۱۵۰، ۱۸۵ با نتایج ابزار دقیق مقایسه شد و به این نتیجه رسیده شد که نتایج به دست آمده از نرم افزار FLAC2D دقیق تر از نرم افزارSEEP/W بوده است.