Investigating the Local Arching Phenomenon in Total Pressure Cells Located in Clay Core Protective Filters and Comparison with Numerical Modeling Results (Case Study: Mamlou Earth Dam)

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Abstract

One of the most important factors affecting the safety and stability of earth dams is arching in a clay core. This phenomenon happens due to difference of elastic modulus of clay and filter materials, which, in turn, causes more settlement in clay core than the sides. This makes transmissions of stress in arched format to lateral filters; hence, stress recorded in pressure cells located in filters increases to more than the above material layers' weight. This led to an increase of arching factor (ratio of stress recorded of total pressure cells to materials weight over these cells) to higher than the unit. This implies that arching is of great importance during the initial impounding of dam reservoir, which should not exceed limited value. The problem happened in Mamlou earth dam is local arching in place of total pressure cells installed in filters which has caused decreasing of recorded stress. Accordingly, the factor of arching is less than one. The phenomenon has happened in most of pressure cells installed in filters. This paper, then, has studied the cases happened in the highest section of dam (section 14). In the next part, we have modelled the main section of the dam in finite difference method by FLAC2D. Finally, we have presented the results of comparison between instrument and model results.

Keywords: local arching, modulus of elasticity, FLAC2D, total pressure cells.

1. INTRODUCTION

Safety of large structures made by human always requires a comprehensive and detailed understanding of them. In the case of earth dams, as the most complex geotechnical structures, the best known structural failure reason is defect in construction, which, in turn, leads to instability in dam body [1], [2], [3] and [4]. Rock fill dams with clay core are desirable among engineers and societies largely due to protection against natural hazards and also cost-effectiveness. As a result, they have developed rapidly in recent decades [5], [6], [7] and [8]. Failure of high earth dams with central impermeable core and two permeable shell on both sides of core could cause risks for communities in downstream. This has led experts and scholars to carry out extensive studies on the same issue. Dam safety evaluation is a complex issue that requires a detailed analysis using instrumentation and analysis by different soft wares [9], [10] and [11].

One of the most important parameters to be taken into consideration is pressure. In order to monitor pressure, it is of great importance to place pressure cells in pre-determined locations in dam body. Recorded data in pressure cells is cyclically collected through data loggers and analyzed. Stability of dam body depends on different items including displacements, pressures, pore pressures. One usual phenomena that happens inside dam body is arching. Arching takes place as a result of settlement difference in clay and filter materials arises due to more filter modulus in comparison with clay. During this process, pressure transition happens from clay to filter. To put it another way, clay behaves like an arch bridge and the side filters act as pile of bridge and carry loads more than overhead load. Before dam construction, prediction is made in different methods to have safe and stable body. Moreover, monitoring is done during construction and in first impounding of reservoir. During our study on Mamlou earth dam, we observed strange phenomena happened in pressure cells located in filters. It was understood that arching factor in these regions is less than unit meaning that it not only does not apply greater burden on the region, but also, loading on the region is less than the overhead. This problem happened in many pressure clusters located in these regions. we called these phenomena as "local arching". In this paper we are going to investigate these phenomena.

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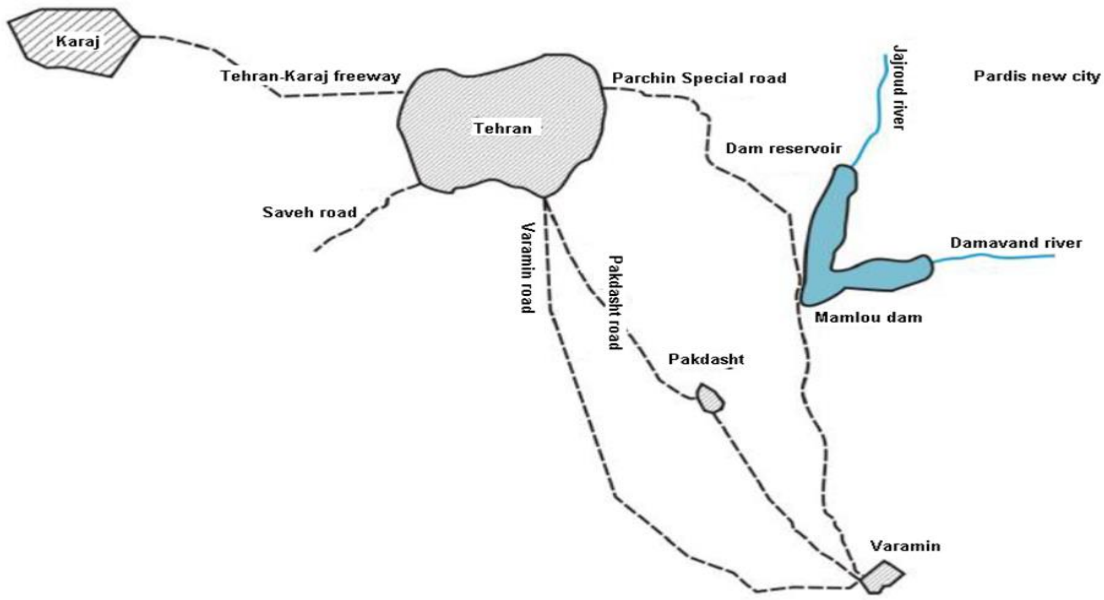
Technical studies concerning geotechnical complex structures such as dams is necessary and the related researchers considered instrumentation a factor for keeping economic interests, which helps to grow the construction and maintenance of development projects [12]. This is quite evident in Mamlou dam instrumentation. In order to accurately evaluate the dam during the construction and exploitation stage, a complete set of instrumentation were installed in 5 sections according to the length of the dam body .Mamlou dam instrumentation consists of total 384 numbers of different instruments. One of the main goals that can be followed through instrumentation of data at the end of dam construction is consideration of the correct Performance of construction and verifying design assumptions and providing alerts to solve the potential problems of the dam. The basic parameters necessary for this purpose in earth dams is measurement of pore water pressure, the amount of stresses in soil and lateral and vertical deformation in dam body [9], [10].

This paper reports the analysis of actual measured pressure in order to estimate arching factor in Mamlou earth dam. With rapid growth in computer processing power and speed, it is not surprising that many engineering problems are solved through analysis or modeling. Today, these soft wares are highly optimized (Siva Kumar and Singh, 2016) [13]. FLAC is a software is used for engineering calculations. FLAC software, which is known as an explicit finite difference based on lagrangian analysis functions, was used to model the main section of Mamlou earth dam (section 14-14) by using Mohr-Coulomb elasto-plastic model and also through data analysis instrumentation. Furthermore, through back analyses, the actual parameters of dam body materials were extracted. In this way, we were able to accurately assess our design assumptions with actual conditions. This analysis focuses on pressure and displacements, and the available monitoring data entails a total of nearly 8 years including part of the construction phase and stage of first filling of the reservoir (2 years), and 6 years of its operational Time.

2. MAMLOU EARTH DAM

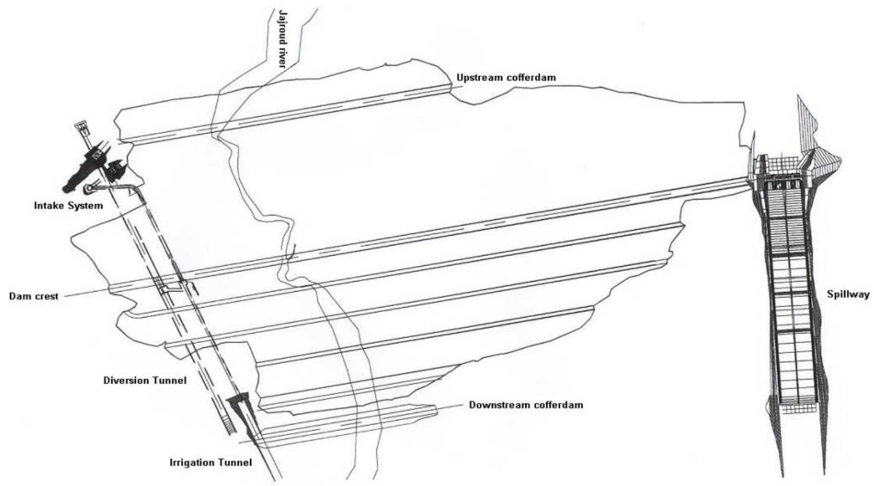
Mamlou earth dam shown in Fig.1 is constructed about 2.5 km downstream the accession of Damavand river to Jajroud Rivers in a place called "gate" by Longitude and latitude of 51.7880˚ and 35.5840˚, respectively which is about 45 km southeast of Tehran. In upstream of the dam is Pardis city and at the downstream of the dam is Pakdasht city located in about 17 and 15 Km distance respectively. Mamlou earth dam is 89m high from the base and 86m high from river bed and the length of crest is 807m (Table 1). The construction of dam began in 2002 and was completed in 2009. First impounding of reservoir started in 2008 February.

(a)



(b)

(c)



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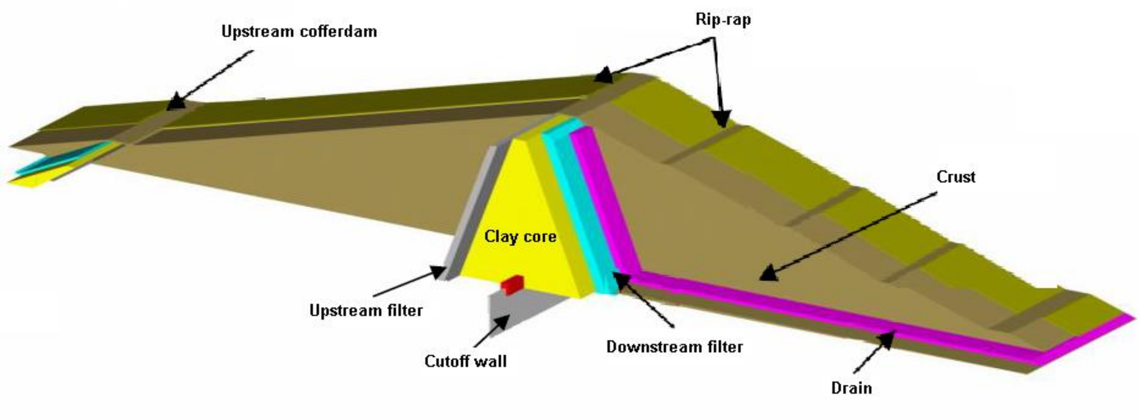

Fig 1. (a) Geographical location of Mamlou earth dam. (b) A general view of Mamlou earth dam. (c) General construction plan and layout of the Mamlou earth dam. (d) Zoning of Mamlou earth dam.

Table 1: General characteristics of the Mamlou dam.

characteristics	estimate
Maximum height	89m
Crest length	807m
Crest width	10m
Crest elevation	1308m
Dam volume	7.17×10^6 m^3
Reservoir volume	2.5×10^8 m^3
Normal water level	1303.5m

3. ANALYSIS OF MONITORING RESULTS

This section deals with dam behavior around the pressure clusters situated in filters. Data collected during dam construction, first impounding and then, operation period, is used for analysis. There are numerous pressure cells that are facing local arching. Therefore, we have chosen one critical instrument which is located in highest instrumentation section of dam body (section 14-14). Fig 2 shows the arching factor and stress changes in PC14-1 which is installed at upstream filter and is at bottom level interface of foundation and filter. As shown in fig 2, arching factor is less than unit which is unusual. According to equation 1, for arching factor (A) increases as with P_y As a result, we can claim that arching factor should be more than unit while this is completely different. In this experiment, we found that this cannot happen while there is arching in clay core. In our argument, then, the only reason is local arching which happens locally around the instrument. In other words, materials around the instrument is in condition that settlement does not happens equally so stress transmitted to beside the cluster that, in turn, it causes less pressure on the pressure cells and accordingly, arching factor decreases less than unit.

$$A = \frac{P_v}{\gamma h} \tag{1}$$

Where $\mathbf{P_v}$ is vertical pressure, γ is special weight and **h** is height of building materials on the instrument.

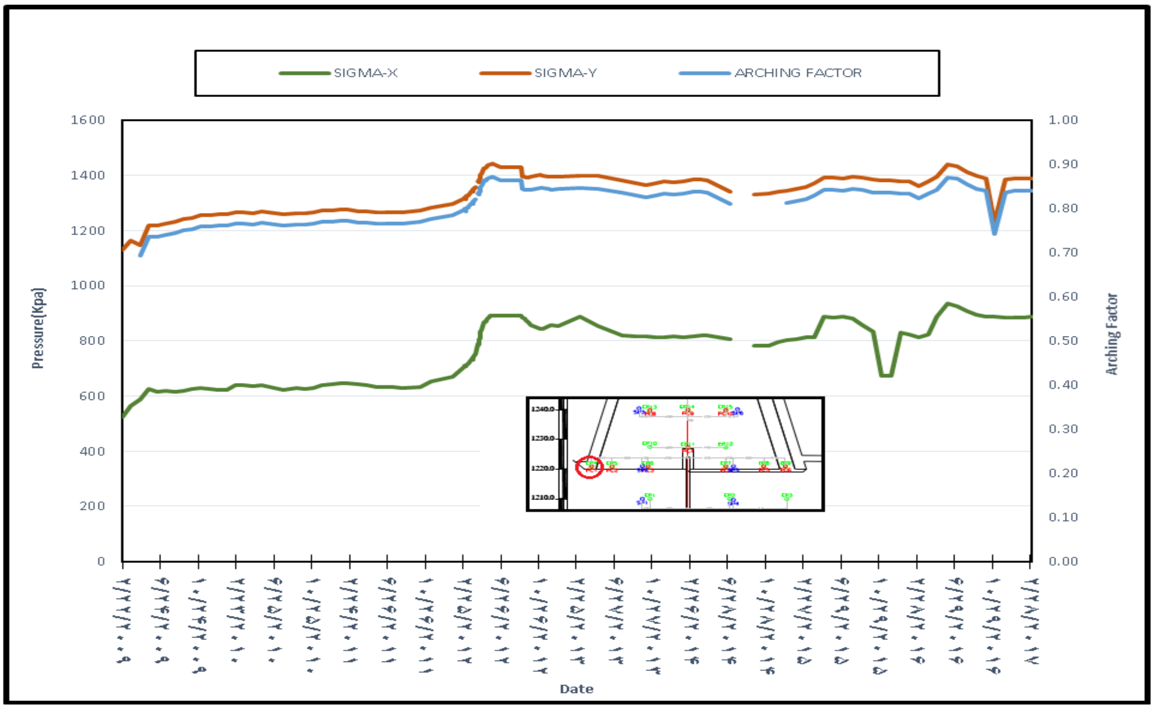

Fig 2. Arching factor and stress measured in pressure cells installed in PC 14-1 cluster

4. NUMERICAL ANALYSIS OF MAMLOO EARTH DAM

In this study, finite difference method was used for modeling dam behavior in order to obtain reliable stress-strain relationship. Mohr-coulomb model, as a conventional model for soil and stone materials, was used for earth dam that provided most adaption with real measurement. FLAC software, which is known as an explicit finite difference based on lagrangian analysis functions, was used to model the main section of Mamlou earth dam (section 14-14) by using Mohr-Coulomb elasto-plastic model. Fig 3 shows the numerical model created in FLAC. Fig 4 shows the vertical stress changes during construction of dam body. According to this graph, it is completely obvious that vertical stress recorded in instruments is lower than the numerical results. Thus, it directly affects arching factor to decrease less than unit.

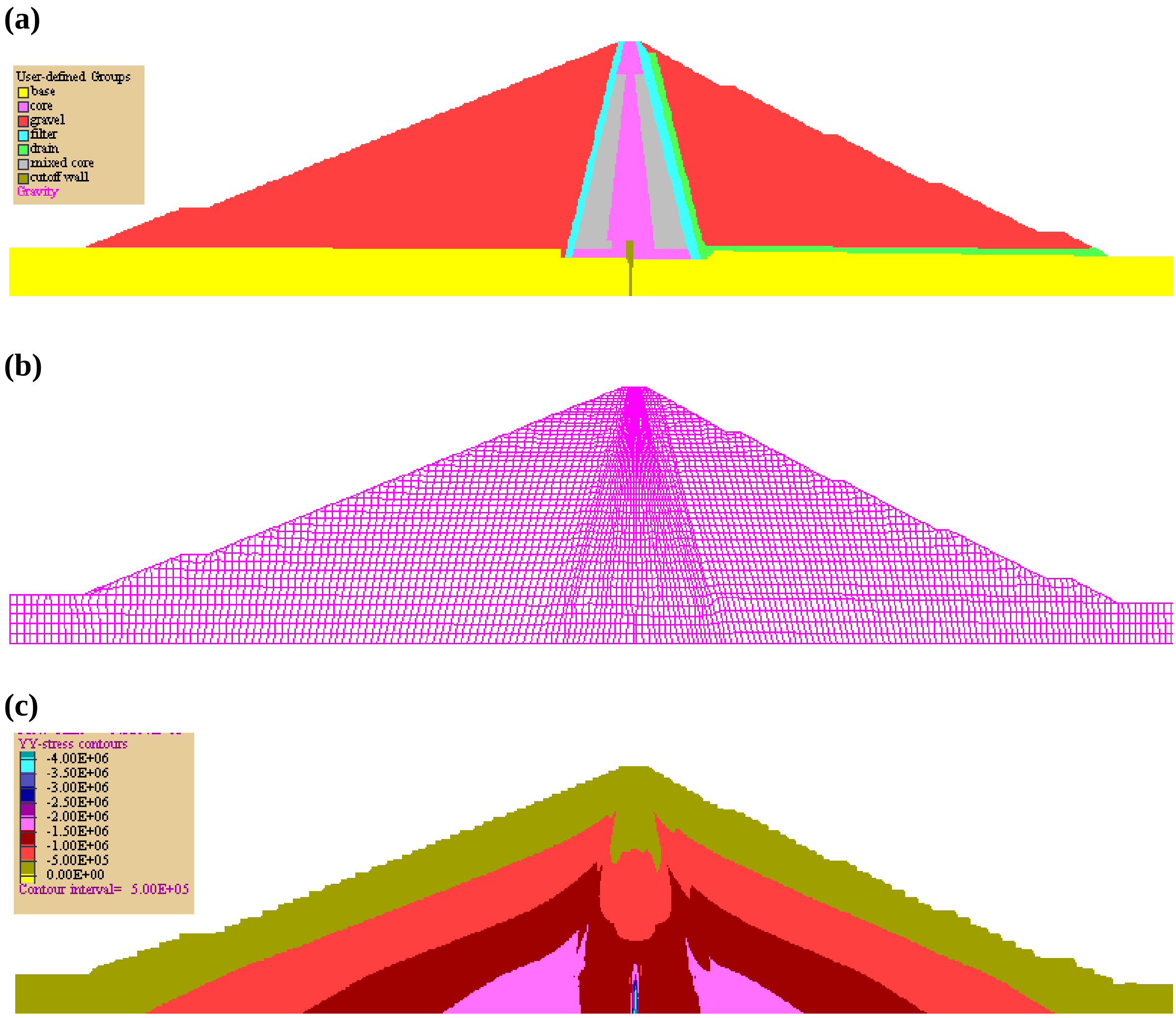

Fig 3. (a) Regions of dam body (b) meshing considered for numerical finite difference method (c) numerical result for vertical stress obtained in dam body at the end of construction.

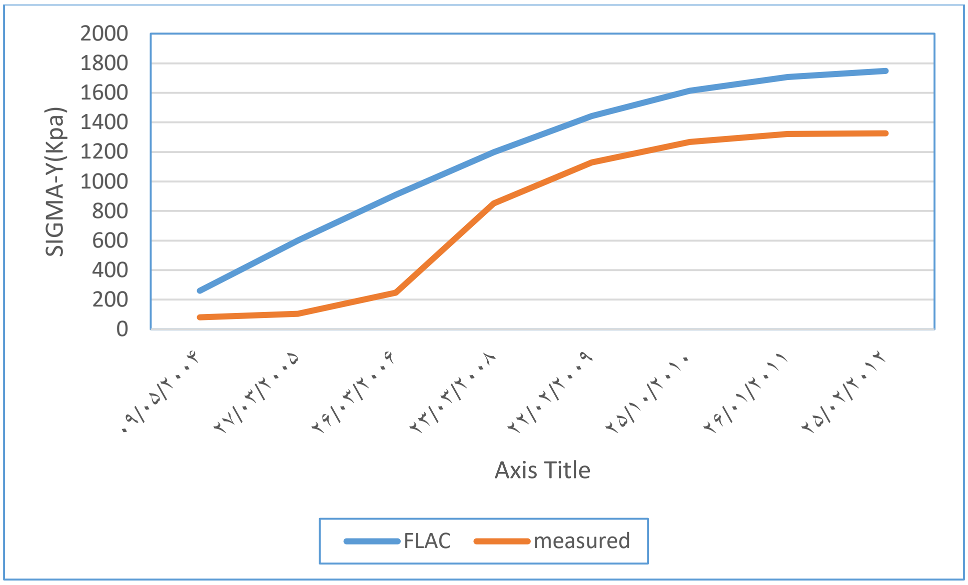

Fig 4. Vertical stress changes in modeling and measurement at the end of construction

5. CONCLUSIONS

The pressure characteristics of an earth dam during construction and operation phases were investigated in this research study. Monitoring was carried out for Mamloo earth dam in Tehran province. For comparison, monitoring records were collected during construction and operation phases which mostly focused on pressure and pore pressure records in pressure clusters located in filters. We observed unusual behaviors in pressure cells located in filters as they showed less pressure compared to overload materials weights while arching has happened in clay core and this is unreasonable. Thus, we understood that an unusual event went on around the pressure cells which decreased the stress on the pressure cell and arching factor becomes less than unit. Since this behavior occurs in clay core, we called it local arching. During our numerical study, we observed usual behaviors in dam body spatially in susceptible zones. These results confirmed our argument about local arching around the pressure cells. Differences between normal and unformal pressure records were about 400kpa at the end of construction continued in operation phase.

6. REFERENCES

1. Sowers G, Sally H (1962),"*Earth and rock fill dam engineering*", London (UK): Asia Publishing House.
2. ICOLD. Lessons from dam incidents (1973) International commission of large dams. Abridged ed. MA (USA): USCOLD.
3. Gikas, Vassilis, and Michael Sakellariou (2008). "*Settlement analysis of the Mornos earth dam (Greece): evidence from numerical modeling and geodetic monitoring*" Engineering Structures 30.11: 3074-3081
4. ÖZEL, HALL FIRAT (2012). "*Comparison of the 2D and 3D Analyses Methods for CFRDS. Diss*". MIDDLE EAST TECHNICAL UNIVERSITY.
5. Singh R, Choudhury S, Singh B (2015). "*Wireless disaster monitoring and management system for Dams*". Procedia Computer Science.381-6.
6. Duncan JM, Chang CY (1970 Sep). "*Nonlinear analysis of stress and strain in soils*", Journal of Soil Mechanics & Foundations Div.
7. Xu B, Zou D, Liu H (2012 Jun 30). "*Three-dimensional simulation of the construction process of the Zipingpu concrete face rock fill dam based on a generalized plasticity model*", Computers and Geotechnics.;43:143-54.
8. Mahinroosta R, Alizadeh A, Gatmiri B (2015 Mar 17). "*Simulation of collapse settlement of first filling in a high rockfill dam*". Engineering Geology. 187:32-44.
9. Stewart M, Tsakiri M (2001). "*The application of GPS to dam surface monitoring*". Journal of Geospatial Engineering; 3(1):45-58.
10. Rohaninejad M, Zarghami M (2012 Mar 31). "*Combining Monte Carlo and finite difference methods for effective simulation of dam behavior*". Advances in Engineering Software; 45(1):197-202.
11. Athani SS, Solanki CH, Dodagoudar GR (2015 Dec 31). "*Seepage and Stability Analyses of Earth Dam Using Finite Element Method*". Aquatic Procedia. 4:876-83.
12. Wymore ML, Van Dam JE, Ceylan H, Qiao D (2015 Dec 31). "*A survey of health monitoring systems for wind turbines*". Renewable and Sustainable Energy Reviews. 52:976-90.
13. Zhang WG, Goh AT (2013 Mar 31). Multivariate adaptive regression splines for analysis of geotechnical engineering systems. Computers and Geotechnics; 48:82-95.