Behavior analysis of ghale chay earth fill dam using instruments data

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Abstract

The Analysis of earth fill dam behavior during construction first impounding and operation periods. May help to recognize any possible destructive phenomena such as high water pore pressure, non-uniform settlements, excessive leakage, piping, and arching etc. In this research, the behavior components of Ghale Chay earth fill dam are investigated using instrumentation data. These components are: water pore pressure, total soil pressure, settlement in foundation and dam body. Various instruments installed in four different section of dam including: piezometers, settlement gages, inclinometers, total pressure cells and stand pipes. The research results indicate that the water pore pressure in the clayey core reduces in flow direction. For different reservoir water level pore pressure is nearly constant downstream of cut-off wall located in dam foundation (changes less than 10%). Maximum settlement occur at cross section No.2 of dam is equal to 816 mm (equal to 1% of dams' height) is seen at 43.7% of dam height.

Keywords: Earth fill Dam, Behavior Analysis, Instrumentation, Settlement, Pore pressure.

1. INTRODUCTION

The safety of embankment dams depends on accurate designing, construction and monitoring the real behavior of dam during the periods of construction and exploitation . recognition of design parameters are needed for accurate and stable designing in the future of which the geotechnical parameters are the most important ones [1]. Scouring, high pore pressure and hydraulic gradient in foundation and body of dam are the most recognized factors in dam's failure [2,3]. In this study, Ghale Chay earth fill dam with vertical and oblique clayey core and 85m height from rocky foundation was evaluated as a case study. In order to investigate the dam's behavior during the construction period, the first impoundment and exploitation time, the settlements, pore water pressure, total pressure and horizontal displacements were studied.

2. PORE WATER PRESSURE

The pore water pressure development in embankment dam's core is one of the main factors which has an important role in stability of dam and soil mechanics. Increasing the pore water pressure can decrease the effective stress resulting in lower shear strength -that has a direct relation with effective stress, and consequently the stability of dam is reduced. Due to the high importance of this subject, the reasons of development of pore water pressure in embankment dams and effective factors on it are mentioned as below (13):

1. The type of materials of dam's core: The type of soil can have effect on pore water pressure from two points of view including compressibility and permeability of soil. These two factors have opposite effects. Compaction of soil causes reduction in void ratio and permeability. Soil compaction that occurs through increasing the water content and pummeling the soil, affects the pore water pressure during dam's construction. According to USBR recommendation, if the core's materials are compacted with a water content between 1% and3% under optimum water content, the pore water pressure will change in an acceptable range.
2. The drainage condition of soil: Existence of drainage around core causes dissipation of pore water pressure. This causes an appropriate water flow and decrease the pore water pressure.
3. The filling speed: Increased overburden is caused due to increased height of filling which can cause development of pore water pressure in embankment dam's core. Increment of overburden causes lower soil porosity and higher saturation of soil and because of fully saturation of materials the pore water pressure

develops. So by controlling the filling speed in a way that the pore water pressure in core can be dissipated, the increment of pore water pressure will be controlled in order not to exceed the confidence interval.

4. The saturation degree of materials: Saturation degree has a direct relation with developing and increasing the pore water pressure and as mentioned before, by fully saturation of the materials the pore water pressure develops and before fully saturation increment of overburden leads to higher saturation degree.
5. The impoundment velocity of dam's cistern: The impoundment increases the pore water pressure and decreases the effective stress in dam's core and the probability of sliding or piping in core's upstream increases.

3. SETTLEMENT

Deformations of an embankment dam start occurring during the construction of the dam. These deformations are caused by the increase of effective stresses during the construction by the consecutive layers of earth material and also by effects of creep of material. Later, the rate of deformations decreases generally in time, with the exception of variations associated to the periodic variations of the level of the reservoir and, in seismic zones, to the earthquakes. Intensity, rate and direction of movements, in a specific point of thebody of the dam or its crest, can vary during the various phases of the construction and the operation of the reservoir. [4]

At the different elevations and in different zone types may occur the variations of stresses what can be caused by differential settlements between the core and the upstream and downstream filter zones. If the core is more compressible than the upstream and downstream filter zones, it settles more under its weight than the filter zone and, by the effect of arching, core mass leans on stiffer filter zones. This causes the reduction of vertical stresses and consequently the lateral stresses develop towards the base of the core. This phenomenon can cause a hydraulic fracturing and a risk of erosion of the fine particles of the core. [4]

The maximum settlement frequently occurs in 1/3 – 1/5 of dam's height [10]. According to reliable references, the value of acceptable settlement of a typical dam is 1%-2% of the dam's height [11,12]

4. RESEARCH METHODOLOGY

Ghale Chay embankment dam is located in the city Ajabshir, Iran, and its construction process was started on July 31st in 2004 and was ended on April 23rd in 2008. The dam is zoned into two parts, with clayey vertical core until the level of 1670 and with oblique part toward the downstream to the level of 1680.4. The drainage blanket at downstream is used with vertical drainage for safe discharge of leakage water. Also, three horizontal drainage layers are located in upstream shell in order to facilitate quick discharge of water of shell and speeding up the saturation of upstream shell during impoundment. The materials of clayey core and body materials are in GC and GP classification, respectively. The other part of the dam is the cut off wall that is built in order to control the pore water pressure in dam's foundation and water flow from it in dam's foundation and sides. The length of crown, the height of dam from alluvial bed and from bedrock and volume of cistern in normal water level (1676m from sea level) are 336 m, 77 m, 85 m and 40 mm3, respectively.

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5. INSTRUMENT OF DAM

As can be seen from the plan in Figure 1, four sections were instrumented along the dam's axis. Also two sections in the middle part of the valley and in the maximum section and the other two sections were located on abutments and around the average height of the dam. The middle sections 2 and 3 were located in 0+207 and 0+260 kms, respectively and side sections were located in 0+160 and 0+320 kms from the left side.

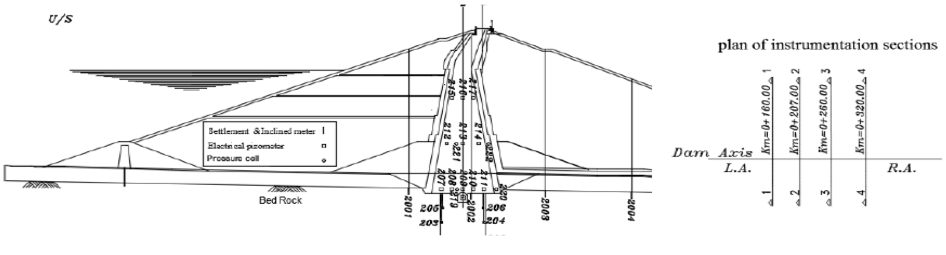


Fig1. Installed instrument in body and foundation in cross section of dam and plan of instrumented sections.

Table 1. number of installed instruments in different sections

total	Section 4		Section 3		Section 2		Section 1		
	Rocky foundation	body	Rocky foundation	body	Rocky foundation	body	Rocky foundation	body	
14	-	3	-	4	-	4	-	3	Settlement/deviation gauge
45	-	6	6	11	6	11	-	6	Electrical pisometer
12	-	2	-	4	-	4	-	2	Total pressure cell

Considering the point that in the present article four parameters of pore water pressure, total pressure and horizontal and vertical displacements were studied, so just the location and number of electrical pizometers, total pressure measurement cells, settlement and deviation gauges have been mentioned. In order to control the condition of pore water pressure during the period of dam's construction and control the depression amount of water energy from core in seepage time, in the sections with maximum dimensions (sections 2 and 3) three rows of electrical piezometers were considered in core. The first row was located in a little distance from the contact surface of core and rocky foundation (level of 1600m) including 5 piezometers, and the second and third rows including 3 electrical piezometers were embedded in the middle level of stable seepage line (1621 m level) and in the level that the stable seepage line meets the core (level of 1644 – 1645 m), respectively. In order to control the piezometric pressure in bedrock, 12 electrical piezometers in sections 2 and 3 were installed. In section 2, three rows of electrical piezometers in the levels of 1569.5, 1570.5 and 1587 were installed. In section 3, for controlling the efficiency of cut off wall in dissipation of piezometric pressures three rows of electrical piezometers in levels of 1568.5, 1578.5 and 1586 were embedded. Four strings of deviation gauges were installed for measuring the settlement and horizontal displacements from which two strings in downstream were in distances of 40 and 77.5 m, one string in core in a distance of 4 m and one string in a distance of 25 m from axis were considered in downstream and upstream, respectively. In the instrumentation plan, all the deviation gauges with magnetic plates were used for measuring the settlements. Two total pressure measurement cells were embedded that one of them was in the core and along the axis (level of 1598 – 1600 m) and one of them was installed in the same level into the downstream filter. Two pressure cells were installed at the level of 1621 m near the dam axis and the downstream filter.

In the sections that were on the abutments (sections 1 and 4), two rows of electrical piezometers were considered in the core. The first row consisting of 3 piezometers was located in the level of 1621 – 1625 m with a short distance from the contact surface of the core and rocky foundation and the second row consisting of three piezometers was located in the level of 1643 – 1644 m. Two pressure cells were installed at the level of 1620 – 1624 m near the dam's axis and downstream filter. In each section there were three deviations – settlement gauges that one of them was in the distance of 20 m from the upstream, and another one was in the distance of 4 m from the downstream and the other was in the distance of 40 m from the downstream.

6. Analysis Instrument Data

6.1 Pore Water Pressure

In the modified soils the pore water pressure develops due to material's weight and other factors. Under several conditions, the safety of slopes of embankment dams is considerably affected by distribution of pore water pressure [6, 7, 8 9]. In this section, because of the similar results, pore water pressure of instrumented sections of cross section 2 are considered. As can be clearly seen in Figure 1, total of 17 electrical piezometers were installed in that section.

According to figure 2, by increasing the filling level, the values of pore pressure increased by increasing the overburden due to the weight of materials. While at the beginning of earthworks the soil had the optimum water content, but by continuing the filling and compacting it, the voids between soil particles decreased and due to water content the soil became saturated. By resuming the filling process and by considering the low permeability of clayey core, the water in the soil did not have any time for drainage and it caused development of pore water pressure.

In order to dissipate the pore water pressure, water should have adequate for drainage that is done through stopping the filling process. As it can be seen until the 16th of May in 2006 that the water level of cistern was higher than the installation level of piezometers, due to cut off wall and upstream berm the dam's body did not affected by the water level of cistern, so it did not have any impact on pore water pressures and their values decreased during filling was stopped . After May 16th in 2006, because of the water flow from upstream berm and saturation of dam's body, the higher water level of cistern compared to increment in filling level, the pore water pressure was affected more.

The piezometer Number 207 that was located at upstream of clayey core, was highly influenced by change of the water level of cistern and by movement toward the downstream its effect on piezometer's results reduced where it had the lowest effect on the piezometer number 211 while for different levels of cistern it had a constant value of 1608.

Figure 3 shows the changes of pore water pressure for second level of piezometers and it can be seen that in the early installation of piezometers they had almost fixed values because of their higher levels in comparison with the cistern's water level and lower overburden compared with the first level piezometers.

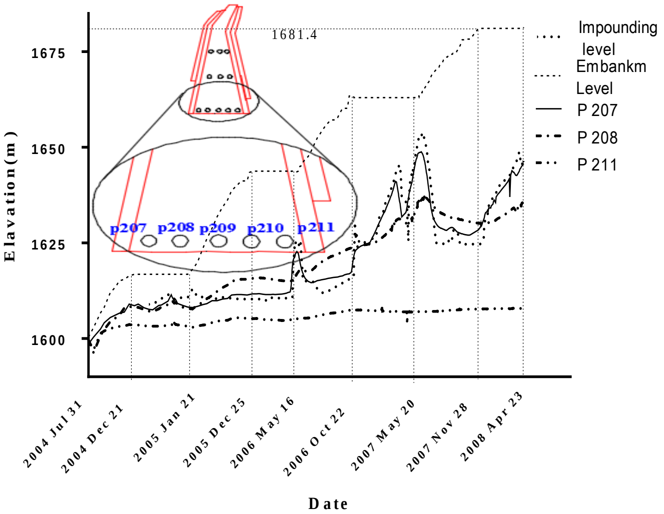


Fig2. Second level piezometric pressure results from piezometers of cross section 2

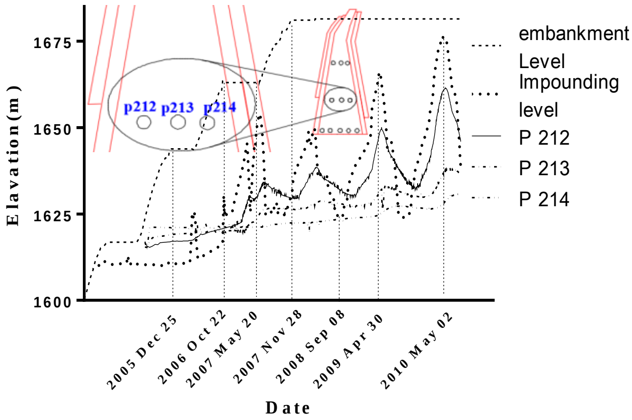


Fig 3 . Second level piezometric pressur results from piezometers of cross section 2

The cut off wall was built under the dam's body in order to avoid scouring and high flow of water. It is able to reduce the water flow by increasing the flow path and decreasing the hydraulic gradient. Figure 4 illustrates the changes of cistern water level versus piezometric pressure of the installed piezometer at the upstream and downstream of cut off wall. It is clear from Figure 4 that increment in water level of cistern increased the ability of cut off wall in dissipating the pore water pressures. The data of installed piezometers at the upstream and downstream of cut off wall are available from April 30th, 2009 and according to Figure 5, the piezometer number 203 that was installed at the upstream of cut off wall had a greater effect due to the short path compared to the piezometer number 204 that was installed at the downstream.

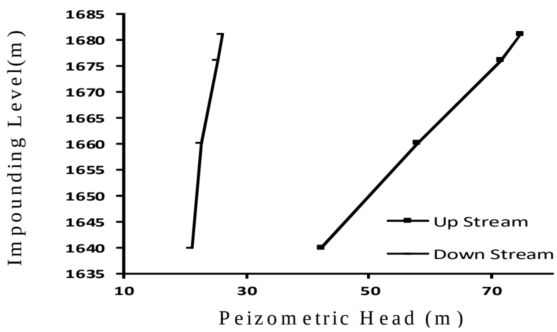


Fig4. The effect of cut off wall in dissipating the piezometric pressure

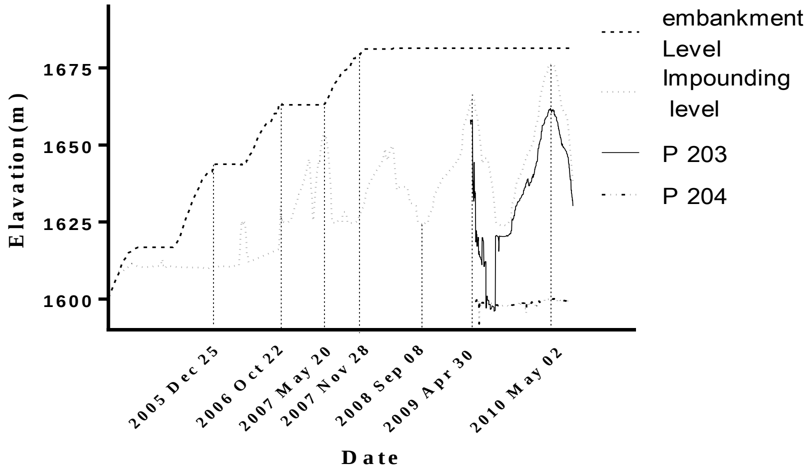
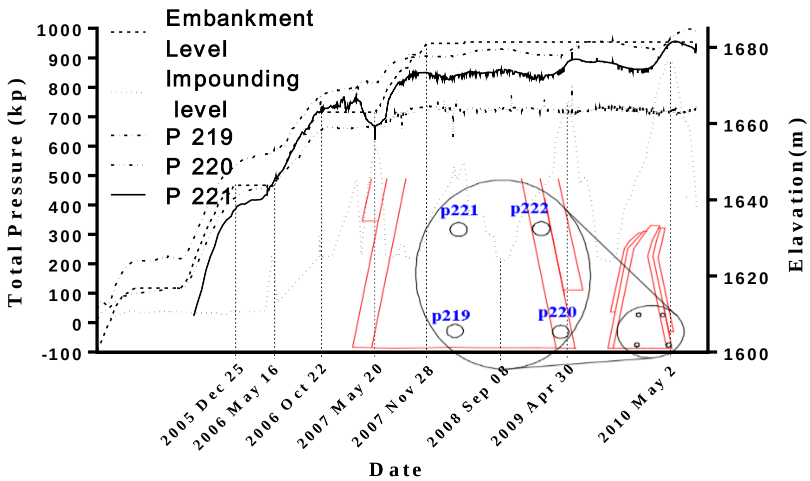


Fig5. The results of piezometric pressure at upstream and downstream of cut off wall

7. TOTAL PRESSURE

In order to measure the total pressure in core at section 2, four pressure measurement cells were installed that the location of each cell and their results are illustrated in Figure 6 as a graph. The graph of number the total pressure measurement cell of 222 was omitted due to the illogical data. During the filling process the total pressure graphs were affected by the changes in filling volume and cistern's water level, but by ending the filling process and fixing the pressure due to the weight of materials the total pressure changes were affected by cistern's water level and other parameters. The total pressure measurement cell of 219 had the higher value than the other cells during the dam's lifetime because of the highest pressure of water head and material's weight.



8. SETTLEMENTS

In order to evaluate the displacements of dam, the data of settlement and deviation gauges in the instrumented section were extracted until the first spillway of the dam on May 2nd ,2010 and were drawn as counters of cross section 2, settlement counter of longitudinal sections and direction of horizontal displacements in longitudinal sections of the dam. Due to the defectiveness of settlement and deviation gauges of number 3001 and 2003, their data weren't applied. Due to the zero height of filling and because there was not any measurement instrument on the left and right sides and in the farthest part of the upstream and downstream the values of settlements were considered equal to zero.

According to Figure 7, maximum amount of the settlement in clayey core until the exploitation time (May 2nd of 2010) at section 2 that was located in a distance of 260 m from the left side, was 816 mm that was equal to 1% of dam's height that was located at 43.7% of dam's height and it was in an acceptable range. Since the settlement gauge number 2003 was defective, the settlement counters of cross section 2 were drawn without considering its data. If its data were available, the settlement counters would be drawn in a pattern of dashed line as it is illustrated in Figure 8.

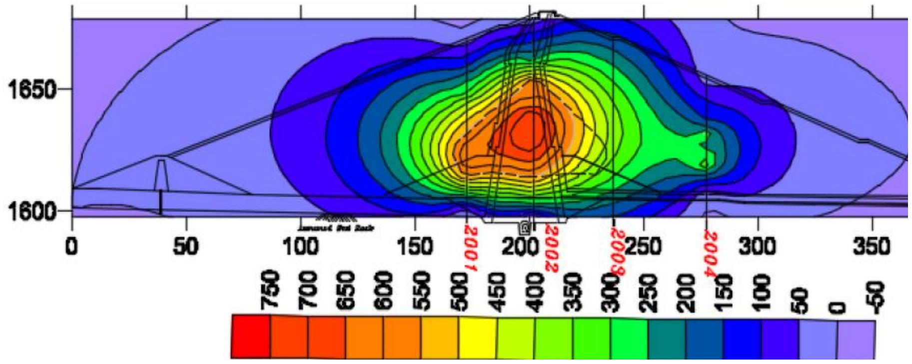
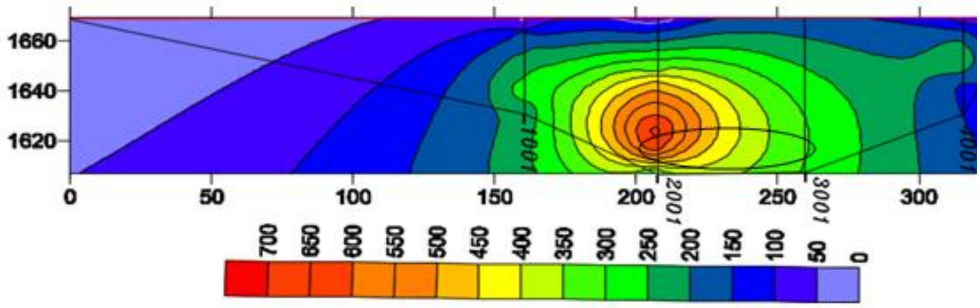
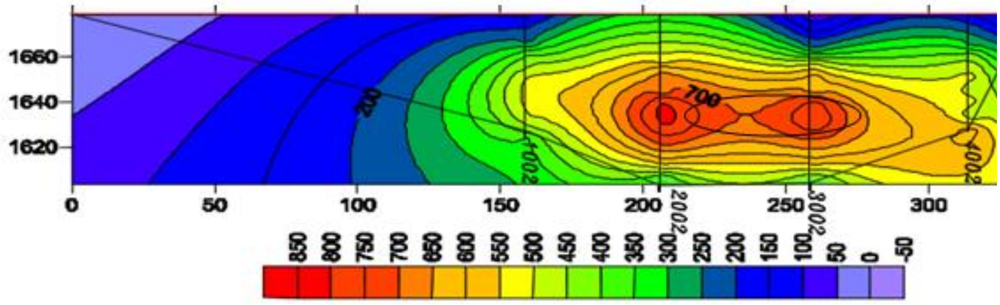


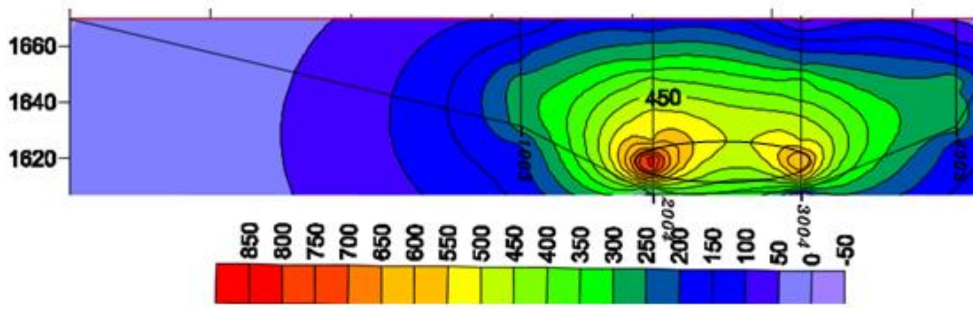
Fig7. Settlement counters of cross section 2 in service time



a- Longitudinal Section of Up Stream Dam



b- Longitudinal Section of Axis Dam



c- Longitudinal Section of Down Stream Dam

Fig 8. Settlement counters of longitudinal sections of dam at service time

The result of the research is summarized as follows:

1- The assessment of instrumentation data shows that the dam behaviors are normal and similar to those was predicted during the dam design period.
2- The increasing rate of water pore pressure inside dam core is close to the rise rate of reservoir water level for first impounding condition.
3- The dam clayey core is appropriately performed in reduction of pore pressure in seepage flow direction.
4- The cut-off wall was built in dam foundation behave properly as the pore pressure is sharply reduced following passing through the wall.
5- The maximum settlement value of 816 mm equal to 1% of dam height is observed in core at about 43.7% of dam height.

10. REFERENCES

1. Sozostak-Chrzanowski, A., Chrzanowski, A. and Massiera, M. (2003), "*Use of Geodetic Monitoring Measurements in Solving Geomechanical Problems in Structural and Mining Engineering*," Proceedings, FIG 11-th International Symposium on Deformation Measurements, Santorini Island, Greece

2. Sowers G, Sally H. (1962), "*Earth and rockfill dam engineering*". London (UK): Asia Publishing House.

3. Szostak-Chrzanowski, A. and Massiéra, M. (2004), "Modelling of deformations during construction of a large earth dam in the La Grande complex, Canada. Technical Sciences Journal, University of Warmia and Mazury, Olsztyn, 109-122.

4. Derakhshandi, M., Pourbagherian, H. R., Baziar, M. H., Shariatmadari, N. and Sadeghpour, A. H. (2014), "*Numerical analysis and monitoring of a rockfill dam at the end of construction (case study: Vanyar dam)*". International Journal of Civil Engineering, 12(4), 326-337.

5. Pagano, L., Picarelli, L., Rianna, G. and Urciuoli, G. (2010a), "*A simple numerical procedure for timely prediction of precipitation-induced landslides in unsaturated pyroclastic soils*", Landslide Vol.7, N. 3, pp 273-289, doi: 10.1007/s10346-010-0216-x

6. Pagano, L., Zingariello, M.C. and Vinale, F. (2008),"*A large physical model to simulate flowslides in pyroclastic soils*", Proceedings of the 1st European Conference on Unsaturated Soils, E-UNSAT 2008: Unsaturated soils- advances in geo-engineering, Durham, UK, pp. 111-115.

7. Toll D.G., Lorenco S.D.N., Mendes J., Gallipoli D., Evans F.D., Augarde C.E., Cui Y.J., Tang A.M., Rojas Vidovic J.C., Pagano L., Mancuso C., Zigariello C. and Tarantino A. (2011), "*Soil Suction Monitoring for Landslides and Slopes*", Quarterly Journal of Engineering Geology and Hydrogeology, vol. 44, N.1., pp. 23-33, doi: 10.1144/1470-9236/09-010

8. Rojas J.C., Pagano L., Zingariello M.C., Mancuso C., Giordano G. and Passeggio G. (2008), "*A new high capacity tensiometer: first results*" Proceedings of the 1st European Conference on Unsaturated Soils, E-UNSAT 2008: Unsaturated soils- advances in geo engineering, Durham, UK, pp. 205-211, London: CRC Press - Taylor &Francis Group

9. Sadrekarimi, J. and Kia, M. (2005),"*Performance of a large dam, field measurements and analytical approach*" 16th Int. Conf. Soil Mechanics and Geotechnical Engineering, Osaka, Japan, PP. 1115-1116

10. Fell, R., Mas Gregor, P. and Stapledon, D. (1992),"*Geotechnical engineering of embankment dams*" Publication, A.A, Balkema.

11. Sherard, J.L., Woodward, R.J., Gizienski, S.F. and Clevenger, W.A. (1976),"*Earth and earth-rock dams*", Publication, Wiley & Sons.

12. Niromand, H.(2000), "*Analisys behavior of Karkheh earth fill dam during construction using instrument data*" thesis of msc degree (in Persian)