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Investigation the Effects of Pore Water Pressure and Arching on Karkheh Earth Dam Considering the Instrumentation Results

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ABSTRACT

The safety of a dam is related not only to accurate design and execution, but although to its correct performance based on monitoring of dam during the first years of operating and loading stages. Dams' monitoring poses a very important situation around the world. In all huge dams pore pressure, soil lump pressures and deformations during building, first operation period, and after that is measured by instruments installed on dam, and the performance of dam is assessed and analyzed. Increase in pore water pressure and its disappearance speed through different times is different due to changes in overload amount and also the difference in core dimension and drainage length. On the other hand the arching phenomena will affect the total stress. The combination of reduction in total stress due to arching and its effects on the changes in pore water pressure should be more accurately investigated, in order to conclude about the effective stress' changes which are related to both of them. Studies and researches done on the settlement results of Karkheh Dam represent the rational behavior of dam and no definite stability problem. The records of pisometer shows that the concentrated pore stress' at core is due to execution and overloads made through filling stages. The relative stability of maximum pore pressure during filling and also before and after performance is a sign of good speed of filling and the hydraulically break down being unlikely.

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INTRODUCTION

The role of an earth dam's core is to make it impenetrate. To make a core, mixed aggregates are laid and compressed at optimum moist. Proceeding the filling process, the lower layer are imposed to higher levels of pressure, leading to a reduction in the spaces without water in them, afterward, the empty spaces will vanish and soil gets to be saturated. From now, the load made by filling process proceeding causes noticeable increase in pore water pressure, and it might be probable to loose soil strength due to effective stress reduction, and hydraulically break down [1].

According to Terzaqi's tensions' rule, the increase in pore pressure in soil, leads to reduction in effective stress; hence, shear strength of soil which is directly related to effective tension, would be reduced. The reduction in soil's shear strength endangers dam's stability. in earth dams the changes in pore water pressure trend either on execution or performing stages is representative of a series of phenomena that has happened or are about to happen.

During dam construction, by measuring pore water pressure, the amount of inclination from design assumptions is known and therefore it'd be possible to adjust the transverse section of dam or modify the construction speed.

In general, weight and seepage are resulting in instability of steeps, in regard to stability investigation of earth dams. Normally in static state, weight force is consistent and has no effect on steep instability, and instability is the result of seepage and pore water pressure made by that. Considering the reduce in soil shear strength by increase in pore water pressure, investigating the pore water pressure has a key role at stability analysis or slip of earth dams body [3].

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During earth dam's construction, at the same time of rising the height of filling and due to upper layers weight and reduce in the volume of soil pores and compressing of the air inside them, the pore pressure is amplified in impenetrable materials. In special cases the rise in pore water pressure may lead in the considerable reduce of shear strength of soil and in one critical case, may lead to instability and failure of dam. The pore water pressure is not related to the water of reservoir, but to the compression state of soil and the water inside it during construction.

Earth dam monitoring, considering the special behavior of soil which is made from three elements of soil, air and water, is very important. An earth dam is first analyzed and designed using the laboratory experiments results on soil deposit samples and also other dam's experiences. At execution stage, by installing instruments, the pore water pressure, deformations and soil lumps pressures are measured and compared to assumptions of design to make sure the consistency of theoretical assumptions to realistic behavior of dam. In case a problem appears in dam's behavior, appropriate course of actions are taken to solve it. Also, monitoring dams could be suitable for future dams design [5].

Monitoring is generally divided to two stages of visual and professional inspection by dam staff and professional engineers and also supervising on the dam performance using instrument results. (Golzari 2010).

The goals of a instrumenting includes producing the necessary information to investigate the performance and safety assessment of dam during construction, performing and servicing, to compare real behavior of dam to design assumptions, observing the real behavior of dam and its performance to improve the design assumptions and advancing the analysis method and increasing the realization of staff about the effects of different parameters on dam behavior.

In earth dams the proceeding of construction stages leads to noticeable concentration of pore water pressure at core of dam and if before finishing filling stage and relative reduction of these pressures performance of dam gets to start, the rise in water head would cause even more increase in pressures in core. Therefore, meeting the second condition of servicing of such projects might encounter problems [8].

This study aims to investigate and monitor Karkheh dam for pore pressures, arching phenomena and deformations.

MATERIALS AND METHODS

A common control in arch dams includes deformation (Panadol, steep-meters, expansion-meters, surveying tasks). To control seepages from spillways, pressure control using pisometer and temperature control is done using thermometers. Figure (1) shows the best positions of putting instruments in a concrete dam.

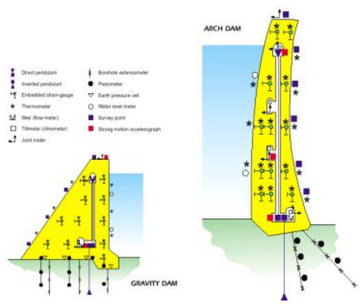

Fig. 1: Locating instuments in a concrete dam.

Location of Karkheh earth dam:

Reservoir earth dam is locating at 21 kilometer far from northwest of Andimeshk city and is situated on Karkheh River. Karkheh river is the third largest river in river after Karoon and Dez rivers, which initiates from Zagros ranges and after passing 900 km ends up to Houral'azim lagoon. The basin of river is as large as 43000 km^2 from Seymareh, Kashkan, Gharasou, Gamasyab and Cherdavel branches. Karkheh dam is the largest earth dam with clay core with a height 127 meters from foundation and a crest of 3030 meters is the 6^{th} dam in the word. The crest of dam counters 234 meters height and the counter of foundation, at the most critical section is 107 meters height from sea level. Figure (2) shows Karkheh dam location.

Dam and water power plant are located on north of Khuzestan county on Karkheh river. Table (1) shows its characteristics.

Karkheh dam site is made from impenetrable Bakhtiary conglomerate with continuous layers of impenetrable lichen. The continuity of lichen layers makes the conglomerates layers totally separate Hydrological, in a way that conducting a handling program it won't affect in other planes of rock. Karkheh conglomerates is consisting from gravels and cobble with different level of cementation and conglomerates matrix is mostly made from sands and silt and sometimes silt and clay. Figure (3) shows topological position of Karkheh dam.

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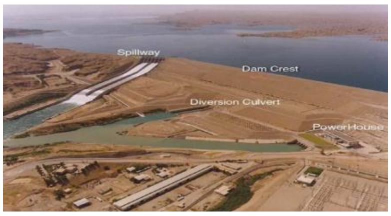

Fig. 2: Karkheh dam location.

Table 1: Technical characterisitics of Karkheh dam.

Dam type	Earth with clay core
Height from foundation	127 meters
Foundation width	1100 meters
Crest width	12 meters
Crest length	3030 meters
Reservoir volume	7800 million m^3
Diversion system	4 water ways with 790 meters length
Spillways type	Opening shout
Resting pool length	157 meters
Galleries of onservation and reaching	1765 meters
On-ground power plant	1000MW(Phase1)
Developable 2 phase capacity	1000MW(Phase1)
Turbine type	Francis with vertical axis

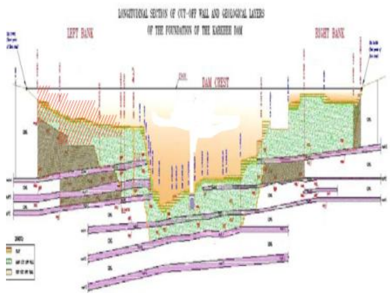

Fig. 3: Karkheh dam's topological postion.

Monitoring and instrumenting system:

To control and survey the performance and behavior of Karkheh dam, a monitoring system according to dam body characteristics, geotechnical state and the position of water proof blanket is minded. The location of used instruments for monitoring dam, considering the site-plan of reservoir in plan are located in a way to be read and controlled easily. The goal of installing this measuring system is to measure these changes during the various life spans of dam:

Outside movement of dam:

To measure and control dam movements, a micro-geodesy system is spreaded around dam site. This network includes the end points of inner instruments of dam.

Pore water pressure: measuring pore water pressure at filling body and foundation, is done with two kind of pizometricinstruments: electrical, and mechanical, which based on the importance of the section and the possibility of installing and execution are installed to several levels.

Water seepage from dam:

The water seepage is collected downstream and is measured and controlled. At supports this will be done through draining galleries and at sides is done by drainage blanket and measuring channel.

Foundation water-proof state: to control the appropriate performance of water-isolating wall, the electrical and mechanical piezometers installed all on the both sides of wall are used. Also, by inspection galleries located at downstream and monitoring wells in those galleries, the level of water is controlled at downstream.

The features of instrumenting foundation and body of dam:

To assure of the stability of dam stability and compare the performance of dam during the construction and servicing stages, a monitoring system, according to dam characteristics, geological state of the foundation and the location of water-proofing wall is used. The number of instrumented sections is 23. Table 2 shows the characteristics of instrumenting foundation and body of Karkheh earth dam.

The main goal of building Karkheh dam, is to control runoff water. Table (3) shows the materials of Karkheh Dam.

According to body and foundation of dam, 23 transversal sections were chosen for installing instruments. Among these, 14 section were enhanced at phase 2 studies, 9 other while executing phase 3, and after first performance in year 2004 to cover better information of instruments. The condition of instruments is represented in Figure (4).

Table 2: characteristics of instrumenting foundation and body of Karkheh earth dam.

Instrument name	Instrument type	Instrument number	Application
RP barometer	Vibrating wire	87	Pore pressure of foundation rock between conglomerates and lynch
EP barometer	Vibrating wire	191	Pore water pressure inside core and filter
SP barometer	Mechanical	134	Assessing the correctness of pore water pressure SP and RP-foundation-body
PC barometer	Vibrating wire	102 cluster of 5	Measuring inner pressure of filling in 5 directions
Vibrating wire	Mechanical	26	Measuring the horizontal and vertical displacement of core's shell
Reference points to determine displacement			Survey points
Headwater between			Observation wells
Recording occurring earthquakes at site	5		Accelograms

Table 3: Materials of Karkheh Dam.

materials features	Unit weight(KPa/m3)	Elasticity Module*104(KPa/m2)	Poison ratio	Inner fraction angle	cohesion(KPa/m2)	Expansion
Un-drained mixed clay core	20.2	3.5	0.40	6	70	angle
shell	20.5	10.2	0.27	39	0	2
Filter and transported materials	19.5	7	0.25	35	0	10
Lynch	19.5	12	0.23	22	70	8
Conglomerate between lynch -1 and -2	22	100	0.30	39.4	5	5
Lynch -1	19.5	12	0.23	22	70	12
Conglomerate between -1 and +2	22	80	0.30	39.4	85	5

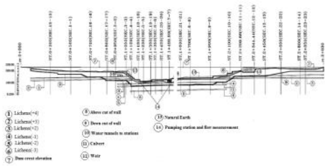

Fig. 4: longitudinal section of dam along with predefined sections to install instruments.

According to height counters of foundation, filling height, and valley depth, the most critical section of Karkheh dam, occurring the most concentration of pore water pressure and the maximum settling wise, is the 5th section at 1+230 station. Hence the highest number of instruments is installed in this section. (Fig 5).

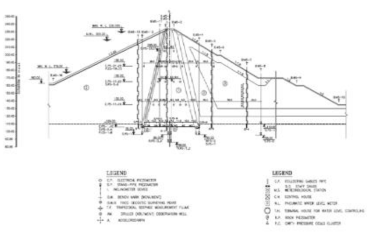

Fig. 4: The location and orientation of instruments in a chosen section of dam.

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Figure (6) shows the cross section of dam at 1+230 station:

1. Impervious core (mudstone mixed with sandy gravel)
2. Sandy gravel
3. Conglomerate or sandy gravel
4. Sand filter
5. Gravel filter and drain
6. Sand-gravel filter
7. U/S slope protection using limestone riprap
8. U/S slope protection using soil cement
9. Plastic concrete cut off wall
10. Pre-coffer dam
11. Main cofferdam
12. Mudstone no. (-1)
13. Mudstone no. (-2)
14. Conglomerate
15. Inspection gallery

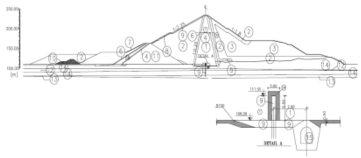

Fig. 6: cross section of dam at 1+230 station.

The height of core filling was the highest during dam construction and at the end of construction stage it will be 127 meters. In total, 948 kind of instruments for pre water pressure and soil and inner movements of dam are used.

Table 4: instruments in use at body and foundation.

Instrument's name	Number in use
Electrical piezometers in foundation and body	278
mechanical piezometers in foundation and body	134
Barometer cells in body	510
inclinometer in body	26

Table 5: general features of dam body and spillways.

DAM type	Earth dam
Maximum width of dam at foundation (meter)	1100 m
Dam crest's width	12m (Elevation of 234 meters above sea level.)
Dam crest's length	3030m
Height from foundation	127m
Total volume at 227 counter	7.3Billion cubic meters
Total volume at servicing counter	5.6Billion cubic meters
Plastic concrete's volume of cut-off water wall	147000m^3
Spillways type	Awesome Shute valve
Spillways's maximum discharge capacity	18260 m^3/Sec
Spillways's length	1125m
Spillways's width	110m

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Locating instruments in Karkheh earth dam:

In general, to monitor and observe the behavior of dam, spillways, supports and water-resisting walls, 1670 number of instruments was installed at essential points and is used. Based on latest report, more than 30 of these instruments experienced total corruption which is reasonable considering the total number of instruments and the dam being an earth dam. Some instruments are recorded every two week, every week, twice in a week, and some once in month, and body's seepage is recorded daily.

To calculate the pore water pressure the following relation is found:

$$u = \frac{p_{a.\Delta}}{v_a + 0.02 v_w - \Delta} \quad \textbf{(1)}$$

That, u is the emerged pore water pressure (PSI), Pa is the absolute pressure of atmosphere at sea level (PSI), v_w is the ratio of pore water volume to the initial volume of filling, v_a is the ratio of current volume of air, right after compression, to the initial volume of filling, and Δ is the ratio of compression to initial volume of filling. The upper relation is written like this in saturation condition:

$$u = \frac{p_a . v_a}{0.02 v_w} \quad \textbf{(2)}$$

To calculate the pore water pressure made in soil, one may use the Skempton parameters (A, B) as follow:

$$u = u_0 + B[(\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)] \quad \textbf{(3)}$$

Table 6: instruments installed in Karkheh dam.

Row	Instruments' name	Summary Symbol	Total installed	Course readings
1	In-rock piezometer	RP	78	Twice a week
2	Electrical piezometer	EP	190	Twice a week
3	Barometer cell	PC	505	Twice a week
4	Cylindrical vertical piezometer	SP	123	Twice a week
5	Inclinometer	INC	29	Monthly
6	Joint-meter	JM	112	Monthly
7	Settling plate	SP	560	Twice a week
8	Observation well	AW	66	TWICE A WEEK
9	Acceloregram	A	6	continuous
10	Shake meter	S	5	Continuous
11	Total seepage station	SG	1	Daily
12	Meteorological station	M-S	1	Code description

Monitoring dam body's settlement:

Table 7: characteristics of iclinometeres that have settlement plates around them.

Row	Instrument's name	Section	Location	Cylinder end level	Cylinder start level
1	I1-1	1-1	core	198.62	233.90
2	I2-1	2-2	core	190.02	233.80
3	I3-1	3-3	core	175.70	233.97
4	I4-1	4-4	Downstream face	128.40	218.91
5	I4-2	4-4	core	134.23	233.98
6	I4-3	4-4	Downstream face	118.80	205.36
7	I5-1	5-5	Upstream face	109.18	217.36
8	I5-2	5-5	core	106.63	234.16
9	I5-3	5-5	Downstream face	108.91	205.09
10	I5-4	5-5	Downstream face	109.58	178.43
11	I6-1	6-6	Upstream face	121.50	218.47
12	I6-2	6-6	core	116.87	234.05
13	I6-3	6-6	Downstream face	116.50	211.31
14	I6-4	6-6	Downstream face	115.98	183.61
15	I7-1	7-7	Upstream face	125.17	217.95
16	I7-2	7-7	core	125.16	234.07
17	I7-3	7-7	Downstream face	125.42	210.72
18	I7-4	7-7	Downstream face	124.63	183.99
19	I8-1	8-8	Upstream face	130.06	218.41
20	I8-2	8-8	core	135.84	234.12
21	I8-3	8-8	Downstream face	136.02	210.61
22	I9-1	9-9	Upstream face	131.50	218.35
23	I9-2	9-9	core	138.13	233.84
24	I9-3	9-9	Downstream face	138.39	211.36
25	I10-1	10-10	core	172.96	231.63
26	I10-2	10-10	Upstream face	172.28	234.0

In which, u_0 is the initial pore water pressure, and $\Delta_{1,2}$ are the changes of normal total stress to initial conditions. Although, since it is necessary to test samples of soil to define Skempton parameters, which is related to saturation level, it seems like the upper relation cannot be used to calculate pore water pressure in practice, in that case, doing the test, water pressure would be measured directly, and ther is no need to determine these parameters. There is no need to point out, without accurate measuring of Skempton parameters by testing samples, the results of this relation are not trustable. Relation 3 could be written as below:

$$u = u_0 + \bar{B}\Delta\sigma_1 \quad \textbf{(4)}$$

In which, $\bar{B}$ is function of A,B parameters.

One of the most phenomena in earth dams is arching phenomenon. This means core being hanged on body which leads to increase in vertical pressure in core. This occurs due to the differences between body and core materials' compressibility. Since core settlements is more than body, core will lays on body. Arching happens mostly around filters and it reduces around center of core. If arching phenomenon is too much it wouldlead to reduction in core and the probability of hydrological failure is appeared. The amount of arching coefficient inside core is derived from relation below:

$$Arching = \frac{\sigma_v}{\gamma.h} \quad \textbf{(5)}$$

In this relation:
σ_v: total vertical pressure in core (KPa)
γ: unit weight of core material (KPa/m)
h: filling height (m)

The smaller this coefficient is the bigger the arching happened inside core is.

Results:

Pore water pressure inside core:

In Figure (7)we see pore water pressure at core to foundation joint at stages that 54 and 84 meters of dam heights were constructed. (Sec 5-5).

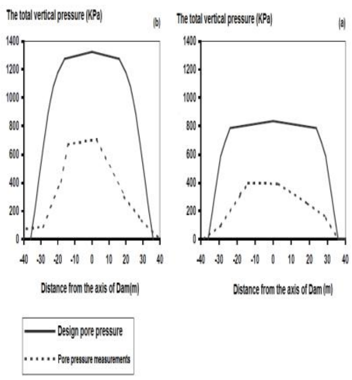

Fig. 5: Pore pressure amount driven from design and practice at Sec 5-5 station 1+230 at core to foundation joint a: 54 metres of dam hegiht is constructed b: 84 metres of dam height is constructed.

It is observable that the major trend of pressure inside core is consistent to pressure trend during design process. Pore pressure during execution is much lesser than pore pressure during design.

In Figure (8), the changes of water head at reservoir along with other foundation piezometer in most critical cross section of dam body (Sec 5-5) is shown. By in-taking water for the first time at February 1999, the trend of water rise at reservoir is was increasing, and this trend keeps on till late March and after that because of over out-take of water against discharge, the reservoir water head is decreasing drastically. Piezometers RP5-3 and SP5-1 that had the most effect on water head increase at reservoir, were electrical and mechanical and were located under upstream filter and 2.5 meters from upstream of cut-off wall, respectively. By comparing the trend of water head changes at reservoir and these two piezometers we can see the speed of water head increase is much lesser than the speed at reservoir. In other words the water head increase at piezometers of upstream of cut-off wall occurs with time delay.

Beside the noticeable increase of pore pressure of foundation at cut-off wall, the piezometers downstream do not show that much of increase. This is vividly shown in Figure (9). The horizontal axes is showing the distance of piezometer from dam axes, and the vertical axes represents the headwater at piezometers. The noticeable difference between two sides of cut-off wall is a sign of the appropriate performance of cut-off wall. At location of downstream piezometers, the piezometers level change from reservoir water level is milder and slower due to the presence and performance of cut-off wall.

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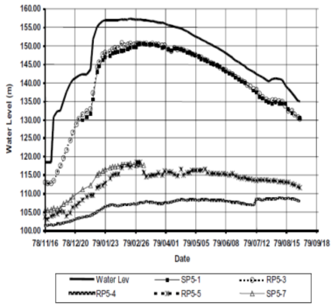

Fig. 6: pore pressure changes during time at dam's foundation at Sec 5-5 (station 1+230).

Investigating soil lump pressure and arching phenomenon:

Figure (9)shows the amounts of total vertical pressure inside core at core to foundation joint at section 5-5. The aforementioned figure shows and compares the induced pressures of soil lump measured by instruments and driven pressure from back analysis when 54 meters and 84 meters of dam filling were executed.(Fig 6-a) it seems when the 54 meter of filling were done, there is a huge difference between the total measured vertical pressure and back analysis. By increase in filling height to 84 meters (4-b) these amount seem to enclose to each other.

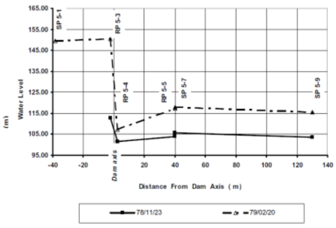

Fig. 7: The pore pressure changes at section 5 during water intake and the time of highest code at reservoir.Pore water pressure inside core.

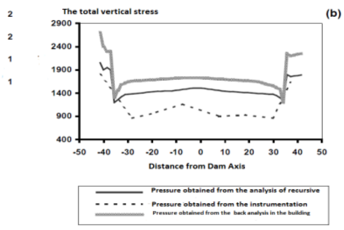

Fig. 10: Aggregates pressure values obtained from back analysis of measured cross(5-5) At the junction of the following core: =54m Implemented the barrier height. b=84m,Implemented the barrier height.

Conclusion:

Kharkhe is an earth dam with clay core and crest length of 3030 meters and height of 127 meters is constructed on Karkheh river. To monitor this dam at construction and servicing stages, about 950 of instruments of any kind are installed. Among them 400 of them are electrical and mechanical piezometers that are mounted in body and core of dam to control the pore pressures. Dam seepage control is done with cut-off wall by plastic concrete which is placed at center of core and continues to needed depth of foundation. Based on measurements done by piezometers inside foundation and sides of cut-off wall, a noticeable drop of water head is seemed on two sides of cut-off wall. This indicates the good performance of cut-off wall and it playing its role appropriately. Inside clay core, the recorded results of piezometers, indicates that the concentrated pore pressure inside core is made by construction tasks and overloads made through filling proceeding. The relative stability of maximum pore pressure during filling stage and also before and after water in-take shows the speed of filling is appropriate and the hydrological failure is unlikely. According to curves related to pore pressure changes inside core during different times it could be summed up that the late water in-take of dam has not yet infected the maximum pore pressure at core center.

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