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INVESTIGATION REASONS AND EFFECTS OF CRACKING ON LONGTERM BEHAVIOR OF KARDEH ARCH DAM

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1. INTRUDUCTION

Dams are constructed for different goals including flood control, Hydropower, and Irrigation, Industrial and Potable water. In addition, Failure of a dam can cause much destruction to life and property. Therefore, safety evaluation of dams is important for reliable behaviour at the future and continuous operation condition. Safety of dams is dependent on various factors which require to be analysed constantly and measures evolved for ensuring their safety [1]. The observed historical behaviour of a dam provides the best indication of the dam's future performance. This paper is a short part the dam safety evaluation of Kardeh arch dam project which has been performed by Tooss-Ab Consulting Engineers[3]. In these studies some cracks were observed on downstream face and parallel to the right abutment on dam body. For the investigation of this problem, a study was carried out using last stage studies reports, construction and operational statements and monitoring data of Kardeh dam. The overall records after comprehensive interpretation of measurement results were analysed .In the present article, after a brief description of Kardeh Dam and problem, according to the collected data beside the results of numerical model reasons for cracking were investigated and effects on long term behaviour of Kardeh arch Dam are discussed.

2. MAIN FEATURES OF KARDEH DAM

2.1. GENERAL SPECIFICATIONS

Kardeh dam is located about 40Km north of Mashhad city on the north-east of Iran and was constructed on the Kardeh River. The dam height is 67 m with 114m crest length that is divided into 15 blocks. The thickness of crown crest block is varying from 8.5m at base (Elv. 1238) to 3.2m at crest elevation (1300). The total volume of the dam is 33000 m3 and the reservoir capacity in normal elevation is about 29 mcm. The main purposes of Kardeh dam are supplying potable water of Mashhad city and irrigation of downstream regions. The dam construction was completed in 1986 and monitoring data since 1993 are available [2], [3]. Geological formation for Foundation and abutment consist of massive limestone belonging to Jurassic period. Fig.1 shows plan and view of Kardeh arch dam.

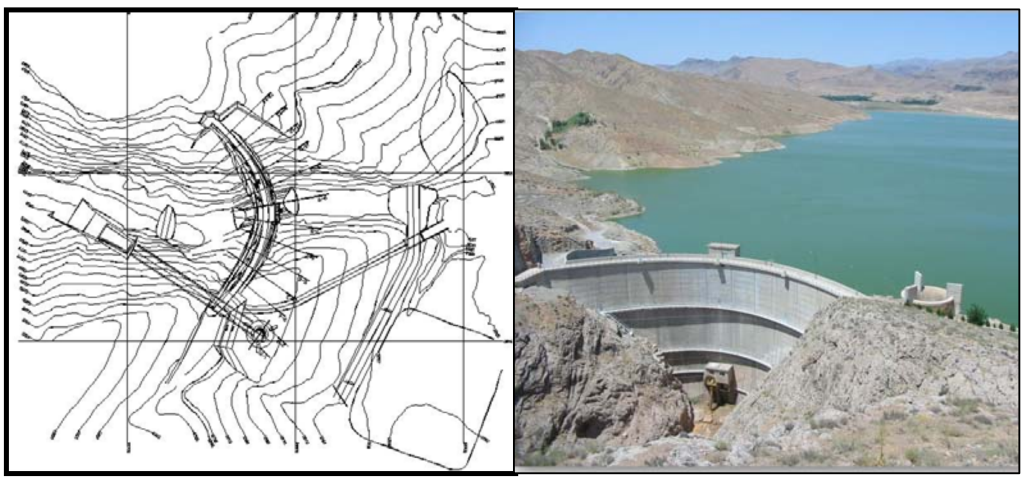

Fig. 1

General view and Plan of Kardeh Dam

2.2. DAM INVESTIGATION

The main instruments used in the Kardeh dam are Direct and Inverted Pendulum, Jointmeter, Thermometer and Uplift measurement. The behaviour of the dam have been discussed in this paper on basis of data collected from the monitoring instruments and observations performed during site inspection since 1994 till 2005. An important consideration in reviewing data obtained from a dam safety monitoring program is the reliability of the monitoring instrumentation itself, hence validity of the measured data was evaluated based on both visual inspection and reviewing of recording data. The instruments are taken reading by manually.

In the process of safety evaluation for Kardeh dam, some set of cracks were observed on the left and right blocks near and parallel to the abutments. These cracks start from one third down of the dam and extended to up with slop of rock abutments. One of the main set of these cracks start from block number 11 (Elv. 1268) to the left side of gallery door on block number 12 (Elv. 1284) and continue toward up from the top right to the blocks number 13, 14. In fig. 2 some main cracks on the right side of dam body are shown. In the current studies, for defining material properties of dam body, beside statistical analysis on concrete test results at the time of construction, Some DT and NDT besides AAR and CAR tests for checking reaction of aggregates were performed [4], [5]. The Maximum depth of Carbonation on Dam body was about 2 mm. On the other hands, numbers of Ultrasonic tests for measuring depth of main cracks and checking some mechanical parameters of dam body with another test results were done. According to the results, the depths of these cracks were more than the specified limitation for instrument (1.5 meter).

Fig. 2

Layout of cracks and test location on the dam body

3. CRACKS INVESTIGATION

In this stage, according to the collected data, reasons for cracking were investigated. These Data were included the monitoring data of dam instruments, some site reports and monitoring of cracks wide for 3 years that explain in the following.

3.1. MONITORING DATA

The data monitoring of the dam are nearly complete from 1994 till 2005. All monitoring instruments are being regularly measured since start of impounding to 1997 weekly, for 1998 and 1999 years twice a month and from 1999 to now monthly. The instruments are taken reading by manually. Concrete temperature has been measured in blocks number 3,5,8,11,13 in three levels 1289, 1273 and 1256 regards to the maximum height of blocks. In fig 3, effects of air temperature and water level on concrete temperature were shown in the crown cantilever (block 8) of dam from 1994 to 2004. Considering to the thickness of Kardeh dam, the seasonal cycle of air temperature have more significant effect on concrete temperature and its distribution [5].

Looking on long term variation of dam reservoir and air temperature since 1993, it can be seen the general trend of Temperature in dam site is normal and harmonic, without any storm or special climate conditions. But in the reservoir, variations of water elevation, particularly reduction of water lake level between 1999 up to 2003 are considerable.

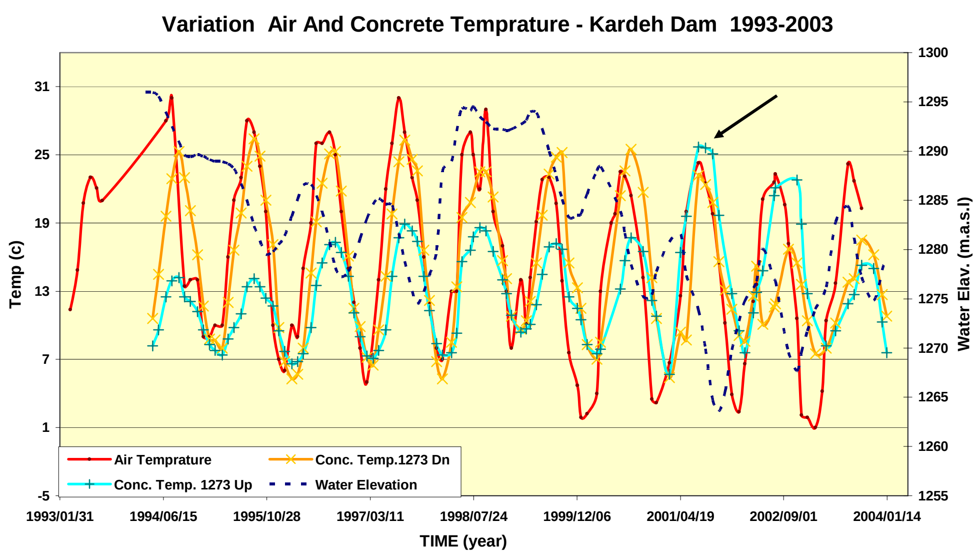

Fig. 3

Effects of air temperature and reservoir elevation on concrete Temperature

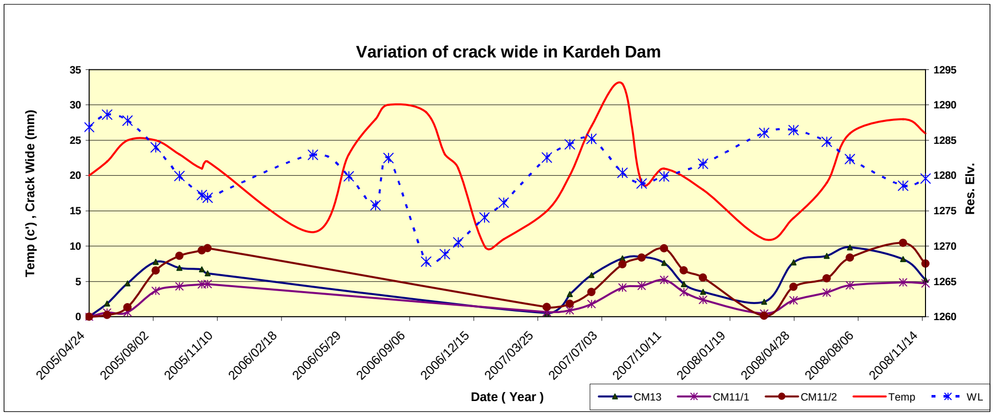

Fig. 4
Variation opening of Cracks with air temperature and reservoir elevation

In that duration, because of drought, reservoir elevation was in the minimum conditions and effects of thermal loading on dam body behaviour have increased. As it shown in fig.3, synchronizing maximum temperature in the summer and minimum water level caused concrete temperature effectively raised in the whole of dam sections over water level.

To monitoring of main cracks, some jointmeters were installed on them and cracks wide have measured since 2005. Variation of cracks opening in blocks 11, 13 with air temperature and reservoir elevation are shown in Fig. 4 from 2005 up to 2008. Some missing data are in 2006. In this figure, after 2007, reservoir elevation varies from 1278 to 1287 and air temperature from 11c' to 33c'. It can be seen that wide of cracks have effectively changed with the air temperature and varies between 0.1 mm up to 11 mm which is considerable for normal conditions.

3.2. Modelling and Analysis

Beside to review measured data, to find out the causes of cracks forming in the Kardeh Dam and to evaluate the effective parameters on them, a finite element analysis before cracking was carried out using ANSYS software. In the computational model, Dam body and rock foundation were modelled with brick elements Solid45 and for more accurate evaluating, vertical joint was considered using contact elements (CONTA52). According to the some construction reports about executive activities during excavations of right abutment, for reason of removing loss materials, the depth of rock foundation had been increased. Therefore, the numerical model was adjusted on real conditions as construction. Load cases considered in the analysis are dead weight, water load and thermal load. The dead load is applied to dam body by modelling construction of the dam in 5 steps with open block joints, for all other load cases, a monolithic dam body has been assumed. For the purpose of the accurate computation, dam-foundation model and material properties was calibrated on the basis of measured radial displacements and concrete temperature data [5]. In the calibration process, using the trial and error method, material parameters of dam model were determined. Calculation for water load is carried out for the different water level as it monitored and for analysing the temperature effects, thermal loading was distributed on dam body by thermal analysis according to the history of seasonal changes of concrete temperature in different position. In the current study, for the reason of crack investigation, apart from normal process for safety evaluation of dam, only special thermal & water load conditions were developed.

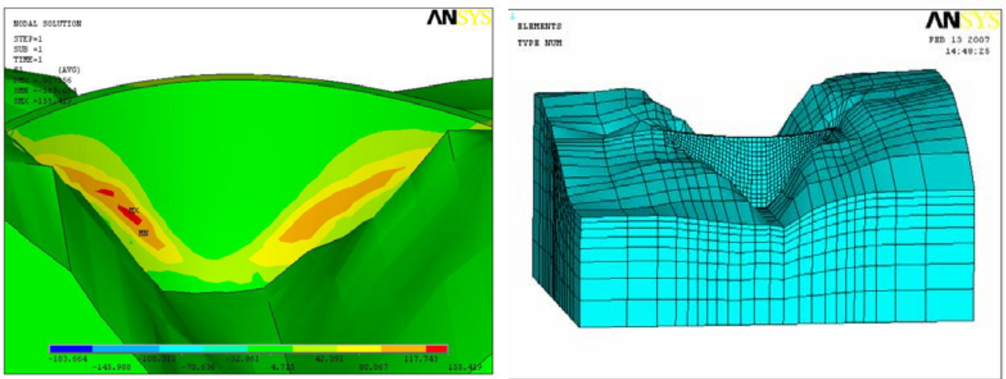

Fig. 5

FE Modeling and stress results in the region of cracking

By analysing and the computational results, in the summer load condition with the minimum water level of reservoir, tensile stress occurred in the down stream face of monoliths adjacent to the right abutment. The Finite element model of dam and foundation and minimum principal stress results in the region of cracking on dam body are shown in Fig. 5. Regard to the thickness of dam which is thin and added restraint in the right abutment, effects of thermal loading particularly in the low reservoir conditions have increased; hence, cracks in this abutment started from horizontal lift joints in block 11 and till to release stresses, cracks have developed to the other adjacent blocks (12, 13). Apparently, developing of current Cracks have been stopped, although wide of them vary with different condition of dam site. As it shown in fig 4, cracks are affected by ambient temperature more than water elevation.

3.3. Long Term Behaviour

To determine long term behaviour of dam, the radial displacements at the crest level in different blocks of dam which were regularly recorded with the help of pendulum were studied [6].

In Fig. 6, the measured displacements at the duration 1993 to 2003 was shown. As it shown, Variation of radial displacement in blocks no. 5, 8, 11 with reservoir elevation and air temperature are plotted. Regard to the water level, the thermal loading is dominated in comparison with hydrostatic loading, and temperature variation is in the normal condition in that duration. Plots the measured displacements and detailed consideration of all prepared data showed that the boundary of measured radial displacements have slightly moved towards upstream.

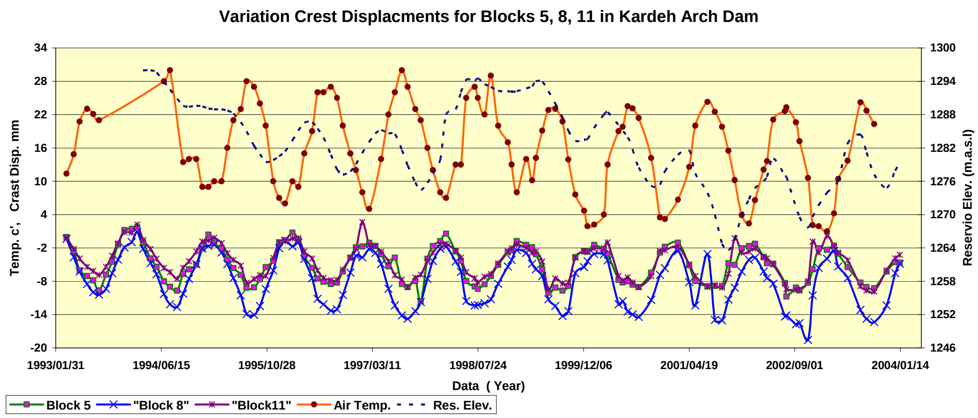

Fig. 6

Radial Displacements in blocks no. 5, 8, 11

The maximum and minimum observed displacements at the crest elevation of crown cantilever (Block 8) are plotted from 1993 to 2007 in Fig. 7. In these graphs, because of clearing, linear trend line was passed between points and variation maximum radial displacements are shown with slop of line. According to the coefficient of variable in linear equation, slop of maximum displacements or rate of variation to upstream direction with time in summer and winter condition are more than 20 and 30 percent.

The displacements envelope on block 8 in 3 cycles with 5 years period (93-97, 98-02, 03-08) was plotted In Fig. 8. As it can be seen, these areas related to the maximum displacements with water level in every cycle were defined. Movement of areas related to the order of operation cycle toward upstream is clear. These movements may be due to the gradual opening of cracks, but the rate of increasing is very slow. Because, the opening of cracks vary with the air temperature and the maximum openings have occurred in the prolonged period of high temperature with low reservoir conditions that According to the measured data, these conditions have been rarely happened during operation of dam.

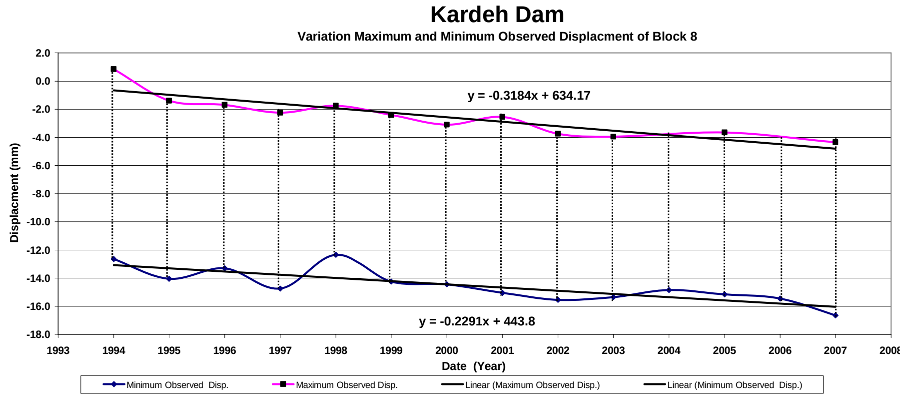

Fig. 7
Variation maximum displacements in blocks 8

It is predictable that the long term effects of this phenomenon will be increasable if intense variation of ambient temperature take place in the low levels of reservoir often times. On the other hands, the special operating management for reservoir elevation in the summer conditions can restrict rate of long term effects on dam body deformations.

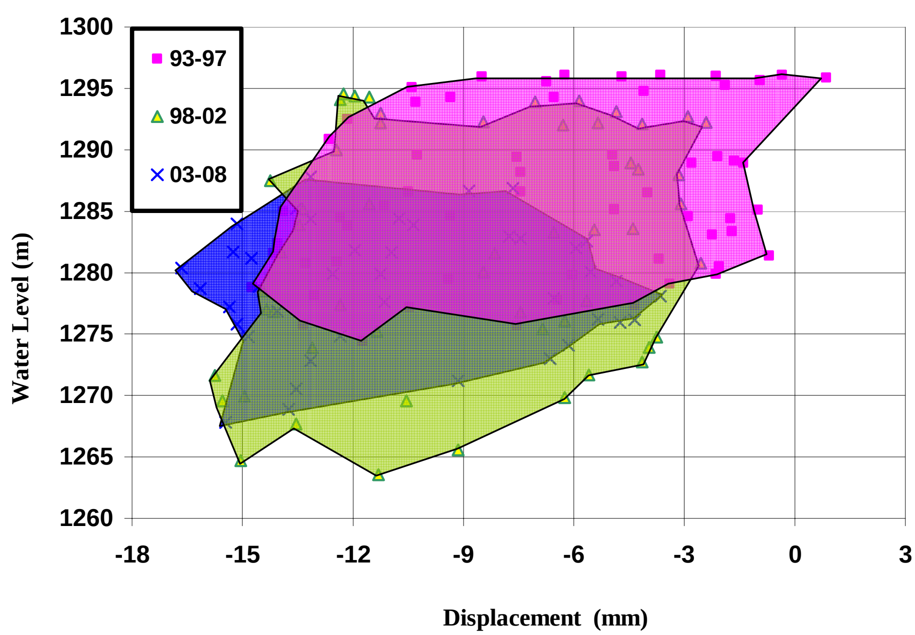

Fig. 8
The displacements envelope on block 8 in 3 cycles (93-97, 98-02, 03-08)

4. CONCLUTIONS

From the results of this study, the following conclusions can be drawn regarding the behaviour of Kardeh Dam:

1. The seasonal temperature particular in the summer conditions are more effective on thin arch dams than the other type of dams.
2. History of construction is very important to safety evaluation of dams and at the end of construction; dam body should be modelled and checked using the reasonable analytical methods.
3. Regards to the gradual variation of some important parameters on the dam, investigation long term behaviour of dam using monitoring data can indicate some faults on dam.
4. In kardeh Arch Dam, in general, according to the trend of movement in the maximum of displacements to upstream and the rate of variations, safety conditions is reasonable and dam behave in a normal manner. These conditions could be controlled and checked by regular safety evaluation studies beside some orders on operating management of dam.

5. REFRENCES

[1]. Chapter 11, Arch Dam, *Engineering guideline for the evaluation of Hydropower projects*, Washington, Dc 20426, 1999

[2]. Safety evaluation report of Kardeh Dam*, Mahab – Ghods Consulting Engineers Co.*, Iran, 1992

[3]. Structural Safety evaluation report of Kardeh Dam, *Tooss Ab Consulting Engineers Co.*, Iran, 2007

[4]. Arch Dam Design, U*.S Army Corps of Engineering, Engineering Manual 10-2-220*, 1994

[5]. S. MALLA, M. WIELAND, Analysis of an arch- gravity dam with a horizontal crack, *Computers & Structures 72*, 1999

[6]. G. LOMBARDIi, R. BREMEN, F. AMBERG, Long term Behaviour of Three Arch Dams, *ICOLD*, Salzburg, Austria, 2001

SUMMARY

The Kardeh Arc Dam is located in the north east of Iran about 40 Km from Mashhad city. The dam height is 67 m with 114 m crest length. Kardeh Dam is a thin Arch which thickness is varying from 8.5 m at the base of crown cantilever to 3.2 m at crest. On the right side of dam body some cracks were observed which are parallel to abutment. In the current studies with review of collected monitoring data and analysis, results are comprised with data of cracks and reasons of cracking and effects of them on the long term behavior of dam body are discussed. Results show small movement on the maximum displacements of dam crest to downstream.

KEYWORDS

Kardeh Arch Dam, Safety of Dam, Long Term Behaviour