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EFFECT OF CONTRACTION JOINTS ON THE STRUCTURAL PERFORMANCE OF ARCH DAM

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ABSTRACT: The tools and techniques in contemporary engineering modeling vision tend to change or update the physical and geometrical appearance of structural components attempts to increase the efficiency of sections. Several studies concerning the stability conditions of the dam components were conducted to examine the structural behavior. such as dam performance evaluation after construction especially research's regarding the stability of aging dams, regardless of any studies of the physical form of the dam components. The dam requires three stages in construction. Firstly, is the investigations stage, followed by the design of dam layouts and finally the construction stage. This research concentrates on the second stage which is the design of dam layouts. Non-Linear analysis was performed under the requirements of the finite element's method on seven models of an arch dam to explore the structural behavior of the concrete cantilever blocks under the effects of different types of loading. Including investigation on the behavior of a dam concerning multiple intervals of contraction joints. Contraction joints were modeled with seven intervals of distances which are 15m,17.5m, 20m, 22.5m, 25m, 27.5m, and 30 meters respectively. Stresses and displacements response of the body dam structure considered as a structural stability indicator for the tension and compression stresses limitation. Nonlinearity measurement in both materials and configurations of the shape of the dam is used to evaluate a maximum and minimum principal stress along the crown cantilever in both of (upstream, downstream) faces. Also, comparisons include the magnitude of displacement along the crest in both faces. The tools for building an information modeling revit package used for the three-dimensional simulation of a dam. Later the seven models linked to finite element tools Abaqus 6.13 package for discretization's and analysis. The results show that the appropriate selection of contraction joints length increased the structural stability condition of the double curvature dam and reduced the risk of failure, especially near the abutments.

Keywords: Arch, Modeling, Stability, Stress, Displacement, Joint

1. INTRODUCTION

Structural contraction joints are considered one of the most important parameter effects accompany with concrete works, especially for megastructure like dams, that is required to cast a huge mass of concrete blocks. The first need for such joints is necessary during construction period for the purposes of curing a high thermal emission from the cement hydration inside the concrete blocks. Non-linearly response for the concrete dam's body execution through divide it in to cantilever parts closed to each other's enables the dam to have Harmonious behavior under suddenly projected loads, it could be the second urgent need. Most of concrete dams need wide studies related to the various variables that may affect by the body of dam's and hydraulic equipment and facilities as well as foundations conditions and the methods of simulating both of rock, concrete, foundation that may reflect a structural response to be closest to reality response. The dams as other structures exposed to static and unexpected loads such as earthquakes, wave, ice, temperature actions on both of upstream and downstream. However, there is one difference between the dam and other structure, which is the direction of the dominant forces, which is perpendicular in the buildings, and corresponding to the dams. A large percentage of the loads on the arch block are absorbed by a dissipate mechanism, which known as the arch action. this mechanism changes the direction of the load away from the center of the dam toward the side abutments. This shows the great importance of dam variables that can be used to increase dam efficiency. One of the most important variables of the physical appearance of dam's body is the distance between joints. when the dam located at third seismic zone or higher become necessary to evaluated using dynamic analysis technique (1). in general, arch dam must model and investigated as linear elastic three-dimensional model. Finite element analysis is the most common technique used for the dynamic analysis. The reason of to consider only linear analysis with high rise dam is to ensure that the dam must be stable under the effect of impact loads, otherwise the actions of designers must take place to change the design layout as it related with the physical appearance and shape of dam. For the stability purposes it is necessary to investigate the

structural behavior of dam by considering nonlinearity in both of configuration and materials. Dams should be reliable during their whole lifetime to avoid any kind of deterioration, weakness. Structural Safety Assessment of a dam under the effect of the earthquake should be based on dynamic material properties of the concrete, modulus of elasticity and dynamic strength of concrete for earthquake actions are determined. Earthquake performance evaluation of an arch dam should be considered many models, material properties and seismic parameter assumption commonly made in dynamic analysis of dam. The contraction joint is known to have very little or no tensile strength and the tensile strength across the lift joints, especially in ageing dams. Contraction joint may open and closed repeatedly and some of the left joints crack regardless of the tensile strength of the intact concrete. The question to be answered, then is whether or not such joint opening and crack will lead to failure mechanism.

2. MODELLING OF DAM

Arch dam modeled as a monolithic structure represented by a single or more layer of finite elements of appropriate and sizes. Additionally, the mesh sufficiently small must be used. The contribution of all significant vibration modes with max harmonic deflected shape is represented accurately. There are two important issues to make modeling, the first is actions or loads modeling. This will define the relationship between loads and the mechanical properties. The second called as structural model. This model associated with mechanical effect forces, expansion with structural effects as displacements and stresses as well as eventual consequences of punctual failures and change of the structural properties or a global failure. scale interval distance of joint is in between 10 meters to 30 meters approximately concerning the Hight of crown cantilever. Because it is nothing that determines the optimum distance between the two joints. This research conducted to considered the different length of contraction joint to evaluated the structural behavior of dam. The innovation of engineering used new mechanisms for updating the physical appearance of components to increase the efficiency of structures and to monitor the effect of contraction joint lengths on the whole dam. Significant of this paper is to find out the effect of the length of the proverbial by the structural response of the dam and to give an optimum border for the distance from one joint to another

2. NUMERICAL MODELING OF DAM

Three dimension of double curvature concrete dam were modeled by revit software package. Basic dimensions of the dam are used, like length of crest, thickness of crest and base, horizontal and vertical curves radius as well as the length of contraction joints. Seven of full-scale model's arch dam formed by building information modeling tools Possesses basic properties and dimensions as 240m Hight of double curvature arch dam total crest length of 775m. The base of the dam is at an elevation of 965 m above sea level and its crest is at an elevation of 1205m.The thickness of the crown cantilever varies from 55.74m at the base to 11m at the crest shown in (Fig. 1,2,3) respectively, Based on static calibration, the material properties for the sound concrete are considered in this paper as mass density =2400 kg/m^3, elastic modulus=36GPa and Poisson's ratio = 0.17 the Cartesian coordinate is used with the origin located at the dam base. Axes x, y, and z are oriented to the right bank, the downstream and the crest, respectively.

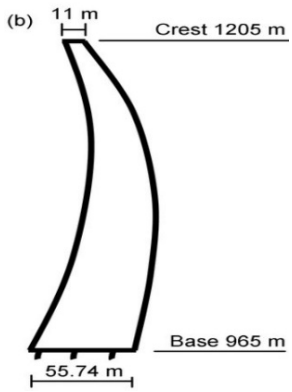

Fig.1 Cross Section of Crown Cantilever

Fig.2 Up Stream with Contraction Joints

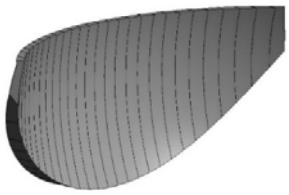

Fig.3 Down Stream with Contraction Joints

4. FINITE ELEMENT MODELS

The dam is idealized as an independent assemblage of three-dimension solid elements as shown in Fig 4. the models are discretized into 22436 3D Solid elements and 35874 nodes [2,6]. Seven model of dame with same basic dimensions the only lengths of joint differ. Distance between joints modeled as shown in Table 1.

Table 1 Analytical cases of double curvature dam

Length of joints	No. of joints	Method of analysis
15 M	53	FEM, Non-Linear
17.5 M	46	FEM, Non-Linear
20 M	40	FEM, Non-Linear
22.5m	36	FEM, Non-Linear
25 M	31	FEM, Non-Linear
27.5	28	FEM, Non-Linear
30 M	26	FEM, Non-Linear

the initial strength of the grouting material in between the contraction joint is disregarded because grouting does not contribute to the joint resistance of the dam. Hard contact and tangential behavior with a simple sliding movement had been defining regarding this issue.

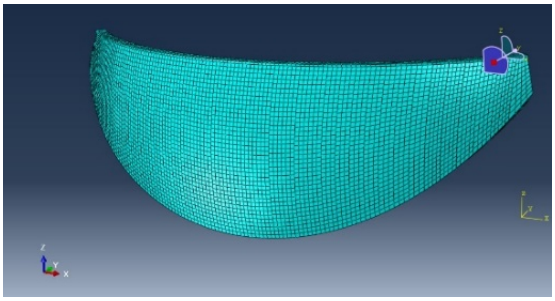

Fig.5 Finite element modeling

5. GROUND MOTION

Global and famous earthquake are used to investigate the behavior of double curvature arch dam. Imperial Valley earthquake Imperial Valley of 1940[8]. It had a magnitude of moment about 6.9 and a maximum perceived intensity of x (Extreme) as per mercalli intensity scale. It was the first major earthquake to be recorded by a strong-motion seismograph located next to a fault rupture. The earthquake was characterized as a typical moderate-sized destructive event with a complex energy release signature. The simultaneous of actions on upstream, cross-stream and vertical components of ground motion are considered. peak ground acceleration PGA of the earthquake motion is 0.3119 g in x direction, 0.21g in y direction and 0.205 in z direction. The three components of the earthquake motion are presented in Fig. 4.

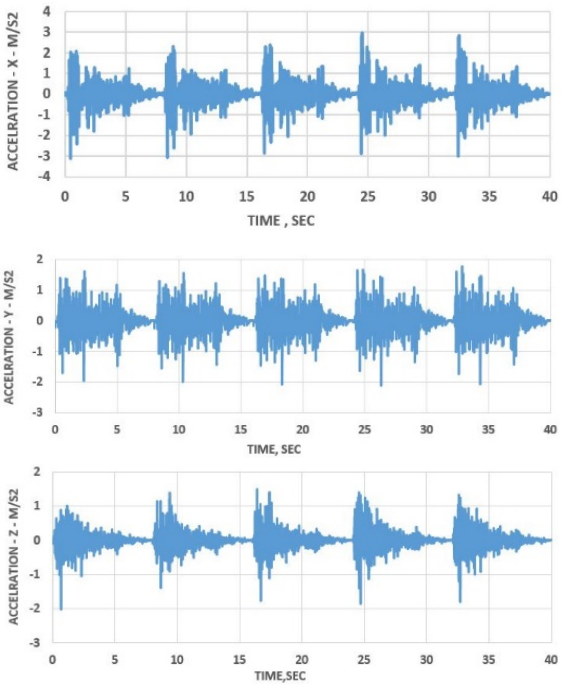

Fig.4 Acceleration components

6. STATIC AND DYNAMIC LOADS

The dam is exposed to static and dynamic loads. hydrostatic load and gravity load (self-weight) always present as static loads. Which is reliability loads on the height and shape of the dam, for example hydrostatic loads is a function of the height of dam varying with water levels. Refer below to a load that were taken into account in this research [1,2, 5,6]:

6.1 Hydrostatic Load

In general, hydrostatic load acting on the upstream and downstream face of the dam. It considers as external water pressure. The hydrostatic load is a function of water height along with the operation live cycle of the dam. Water pressure on the can express equation below:

$$pw = \rho w \, g \, \Delta h \qquad (1)$$

$\boldsymbol{\rho w}$ is water density, g the standard gravity, $\Delta \boldsymbol{h}$ the water depth [1,2]

6.2 Gravity Load

Self-wight loads is the gravity load acting on vertical plane of the dam. the main material of dam is concrete, however there will be some parts such as gates and ancillary structure that will have

another density must to add for the gravity load of concrete. This research considers the vertical gravity load for all concrete cantilever's blocks with most accessories [1,2,5].

6.3 Hydrodynamic Load

Earthquake acceleration caused motion of water in the reservoir. This motion of water causes a hydrodynamic force exerted on the upstream face. as recommended by Westergaard [1,2,4,6] the hydrodynamic force can be marked as equivalent to inertia forces of water volume attach and moving back and forth with dam while the rest of the reservoir water remain inactive. For analysis purpose, dam idealizes to be rigid monolithic with upstream face of body. The water attached to the dams proposed to have parabolic shape. the added mass of water at the location it is obtained by multiplying the mass density water by the volume of water tributary to point i in the formula:

$$M\ added = 0.875\ \rho_w\ A_i \sqrt{H(H - Zi)} \qquad (2)$$

where H is the water depth, Zi the height above the dam base and Ai the tributary surface area at point i. Westergaard added mass is then added together with the mass of the dam at each point of the dam surface.

$$\text{M Total, = M dam + M added} \qquad (3)$$

7. SECONDARY LOAD

Secondary loads are the least weight and impact loads that are considerable importance for a specific dam structure for a particular season. Certain loads are time-dependent. Some of them increase gradually, like sediment and waves loads.

7.1 Sediment Load

On the upstream face, accumulating sediment gradually caused lateral pressure acting on the upstream face of dam. This pressure called a sediment or silt load. sediment pressure is described with Rankin active earth pressure theory.

$$ps = \gamma\text{-}\ hs \tan^2(45^\circ - \varphi/2) \qquad (4)$$

Where $\boldsymbol{hs}$ is the height of the sediment, $\boldsymbol{\varphi}$ the friction angle and $\boldsymbol{\gamma}$ buoyant unit weight of sediment, which is saturated unite weight minus the unit weight of water.

7.2 Waves Loads

Wave load caused by waving acting on the dam face, is generally neglected, the reason is that the magnitude is relatively small as well the load irregular and depend on the location. This loads not consider in this paper. Ice loads Ice loads is only important in location where thick ice sheets for long period of time, ice loads are a function of ice thickness, at locations where the ice sheet expected to be thinner than 0.4 m the ice loads neglected.

8. EXCEPTIONAL LOADS

Exceptional loads are loads that are hard to predict or have a low probability to occur like a seismic load. In case of seismic disturbance, the loads will be generated due to inertia of dam and the retained water. A seismic activity will cause horizontal and vertical accelerations. which are both considered in this paper [1,2,5]. The loads acting to the body of dam can be shown in table (2).

Table 2 Loads case - analytical steps

Load	step of nonlinear analysis	
gravity	static	dynamic
hydrostatic	static	dynamic
silt	static	dynamic
hydrodynamic	-------	dynamic
seismic	-------	dynamic

7. BOUNDARY CONDITION

To eliminate rigid body motion, we must impose boundary conditions. For example, fixed boundary condition, clamped boundary condition and simply supported condition. Boundary conditions either define the loads the at act on the structure, or describe the way in which the structure is supported (displacement boundary conditions). Both types of boundary conditions often involve simplifications of actual structural situation, either to reduce the model size by replacing structure with boundary conditions or because the real state of loading and support is known imperfectly. A consistent set of boundary conditions is required for a unique mathematical solution of the finite element equations. The boundary conditions used is: Fixed - fixed (ux, uy, uz and rotx, roty, rotz) are restraint at the nodes.

8. PRINCIPAL STRESSES

Since S is a symmetrical matrix it can be diagonalized with respected to the finite element theory, its eigenvalues are all real and if they are all different it has orthogonal eigenvectors. This means that there are always three perpendicular facets where the stress is normal to each facet [7]. The shearing stresses become zero and the only stresses on the element are the normal stresses. These facets

are known as principal facets, and their stresses are the principal stresses $\boldsymbol{\sigma}1$, $\boldsymbol{\sigma}2$ and $\boldsymbol{\sigma}3$ in the principal directions: n1, n2 and n3. The principal stresses are illustrated in Fig 6 are usually classified by their size where:

$$\boldsymbol{\sigma}3 \leq \boldsymbol{\sigma}2 \leq \boldsymbol{\sigma}1 \qquad (5)$$

The sign of the normal stress denotes whether the stress is pointed in or outwards from the infinitesimal element. When analyzing stresses in a deformed body the maximal principal stress, $\boldsymbol{\sigma}1$, is used to find the areas of tensile stress and the minimal principal stress, $\boldsymbol{\sigma}3$, is used to find areas of compressive stress [7].

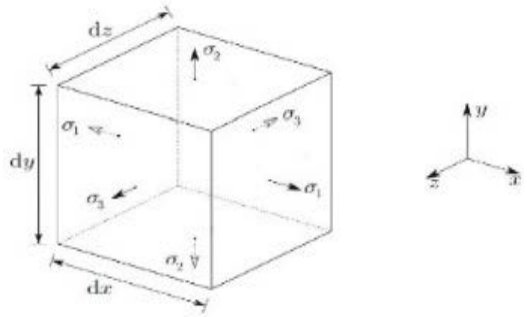

Fig.6 Principal Stresses

9. STRUCTURAL DAMPENING

Considering it is useless to discover the coefficients of the damping matrix from the structure dimension, structural member size and the damping of structural materials used the damping is specified by numerical values for the modal damping ratios. The modal damping ratios include all energy-dissipating mechanisms and they are adequate for analysis of linear systems with classical damping. by considering the modal analysis for the double curvature concrete dam model to assess the modes shape and oscillations that will guide to find the damping coefficient β and γ [9,10] by considering full-scale of modal analysis for the dam to then, by regarding the results of first and second mode. frequencies can be noticed from any two modes as shown in table 3. damping parameters can evaluated as mention in "Eq. 6''.

$$\boldsymbol{\beta} = \boldsymbol{\varepsilon}\,\frac{1}{\omega i+\omega j} \quad , \quad \boldsymbol{\gamma} = \boldsymbol{\varepsilon}\,\frac{2\,\omega i\,\omega j}{\omega i+\omega j} \qquad (6)$$

Where, $\boldsymbol{\varepsilon}$ = 0.05, $\boldsymbol{\omega i}$ frequency of first mode $\boldsymbol{\omega j}$ frequency of second mode selected. The frequencies $\boldsymbol{\omega}1$=8.3774rad/s and $\boldsymbol{\omega}5$=16.143rad/s were chosen for calculation of the Rayleigh damping, using a damping ratio of $\boldsymbol{\varepsilon}$ = 5%, a reasonable estimate of the dynamic response of concrete hydraulic structures, resulted in damping factors $\boldsymbol{\gamma}$= 0.55152595 and $\boldsymbol{\beta}$= 0.00203912.

Table 3 Modal Analysis Results

No. Mode	Eigenvalue Rad/Time	Frequency Cyclic/ Time	Frequency, Hz /Time
1	70.180	8.3774	1.3333
2	74.759	8.6464	1.3761
3	118.84	10.901	1.7350
4	169.21	13.008	2.0703
5	260.60	16.143	2.5693
6	359.22	18.953	3.0165
7	393.42	19.835	3.1568
8	496.44	22.281	3.5461
9	578.78	24.058	3.8289

10. RESULTS AND DISCUSSION

Nonlinear analysis has been performed for seven models of double curvature concrete dam. Each model has been individually analyzed. the models have same dimensional and physical properties, but they differ in the distance from one joint to the next. Structural investigation of concrete dam behavior to evaluate the effect of modeling of joints on the dam response. The results will enable you to customize the optimum distance between the joints. Displacement and stress indicators were adopted as predictive measures for the dam's response. The comparison includes stresses along the crown cantilever and displacement along the crest.

10.1 Max Principal Stress Along the Height of Crown Cantilever

Maximum principal stress along the crown cantilever path at both of upstream and downstream faces investigated for seven models of double curvature concrete dam, the only length of contraction joint is variable in this reach. the behavior of dam can be evaluated with respect to the biggest cantilever (crown cantilever). the 3D modelling of dam can be seen as in Fig (7-8).

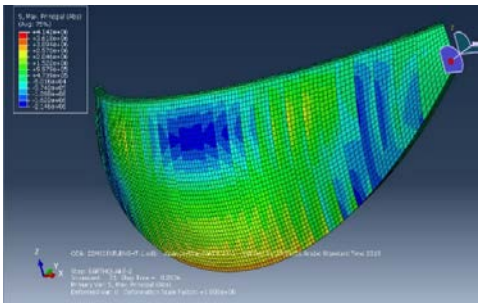

Fig.7 3D Modeling of Dam

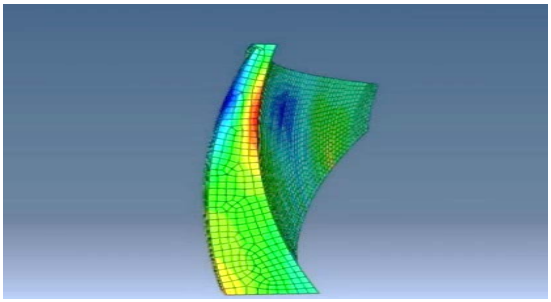

Fig.8 Crown Cantilever Section

The results of the stresses analysis can be viewed according to the change in the length of the joint in the geometric formation of the arch dam.

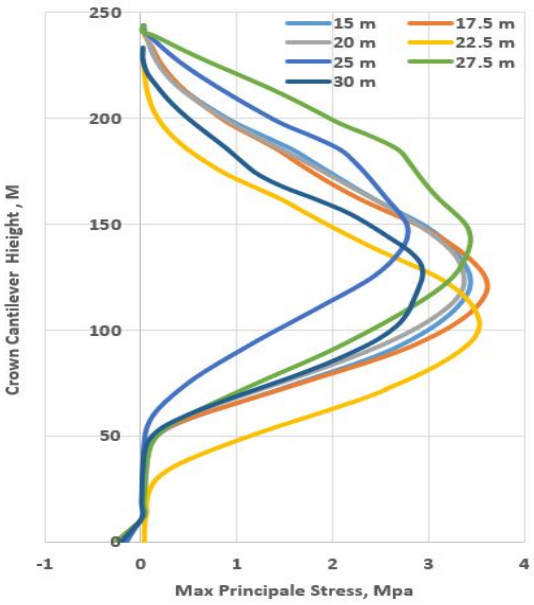

Fig.9 Max principal stress – Upstream

The earlier comparison involved a stress analysis of tension. Which showed the effect of the joint length on the stresses dam response. The results described that the most limited stress was recorded within the model of 25 meters the length. On the other hand, noticed a variation in the tensile position along the crown cantilever. This is a positive response because of the concentration of the tensile forces in the thicker areas especially in the model of length 22.5 m.

Figure 10 confirms the effects of the length of the joint on the response, although the tension states are varied, most values are safe if I want to compare them to the upper boundaries of the tension. The earlier stress evaluation requires another evaluation regarding displacement to touch the basic goal of this paper, which is to choose appropriate limits for the length of the joints.

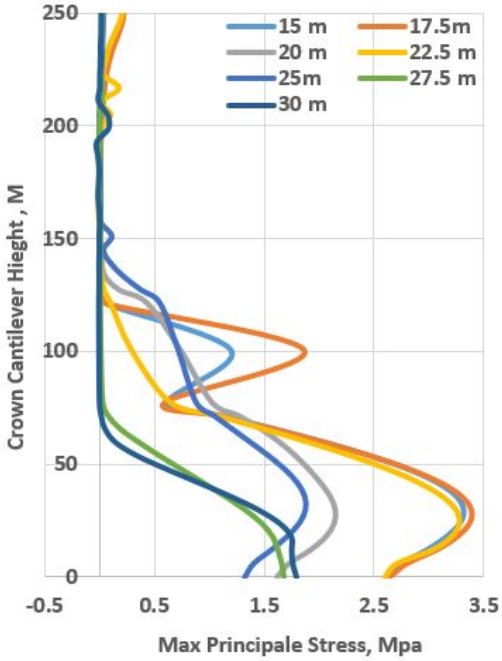

Fig.10 Max principal stress – Downstream

Table 4 Max value of tension stress along crown cantilever.

Up-stream		Down-stream	
Length M	S. Max MPa	Length M	S. Max MPa
15	3.368988	15	3.3147
17.5	3.580948	17.5	3.3672
20	3.365815	20	2.1452
22.5	3.536717	22.5	3.2767
25	2.712936	25	1.8777
27.5	3.436646	27.5	1.6771
30	2.941495	30	1.7994

10.2 Minimum Principal Stress Along the Height of Crown Cantilever

At the corresponding path on crown cantilever block, both faces of upstream and downstream, compression stress can be estimated as in Figs. 11,12 respectively. commonly, Minimum principal stress indicates the compression stresses.

Arch action contributed to reduce the stresses response in the center of the dam's body. The results above showed that there was an effect of the length of the joint on the pressure stress values. Results showed close harmony in the direction of upstream and a difference in the other side. variations of compression stress's response can recognize in Table (5).

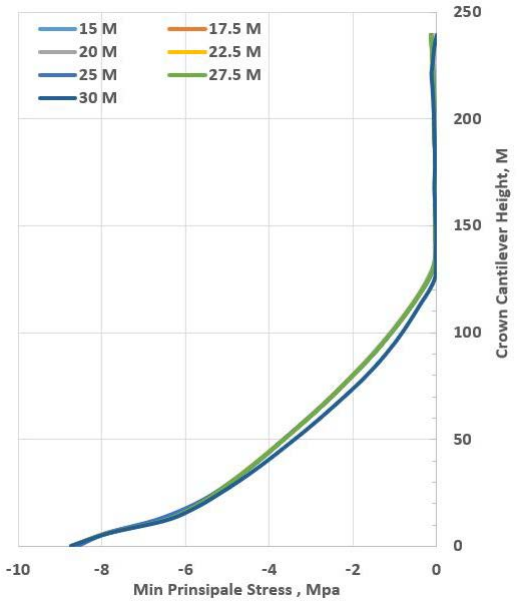

Fig.11 Min principal stress - Upstream

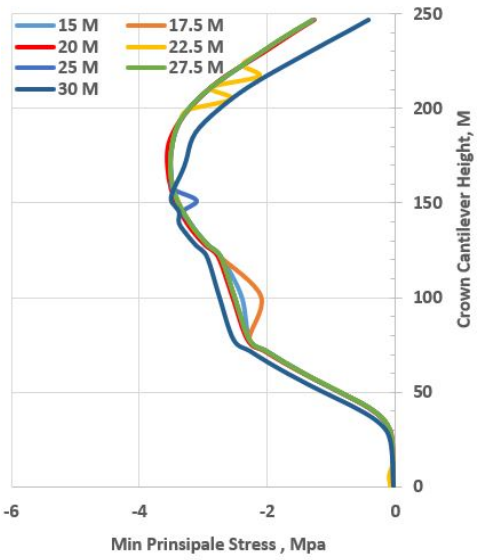

Fig.12 Min principal stresses -Downstream

70.3 Displacements Response Along the Crest (Upstream Face - Downstream)

One of the most important limitations of the structural response of dam is the displacement at the highest point of the structure. Crest is a term given to the upper end of the dam. It has a limited movement path. The drift of this path is restricted by the bonding materials located inside the joints. Any increase in displacement value can induce openings moreover constitute a danger to the dam. In this paper, the movement pattern of the cantilevers blocks along the crest path will be reviewed. displacement responses of the blocks are completely visible on both faces of the concrete dam as well as the maximum joint opening will be evaluated for all seven models under the effect of the above load's conditions. The paths are selected node by node along the crest length. displacement response along crest under the effect of different length of contraction joint can be shown as below.

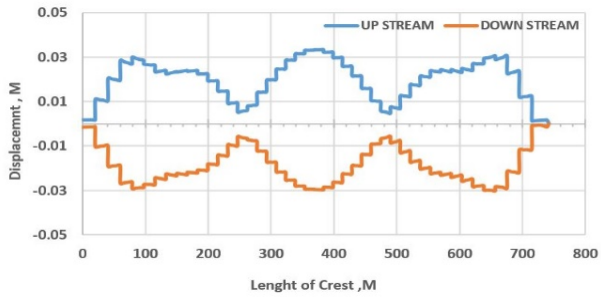

Fig.13 Length of Joint 15 M

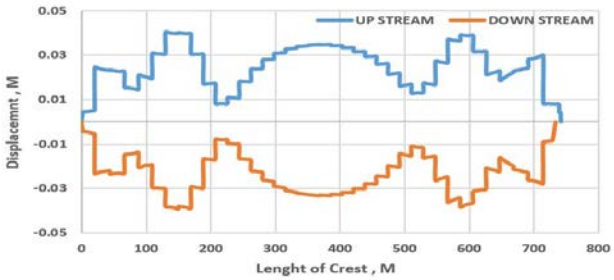

Fig .14 Length of Joint 17.5 M

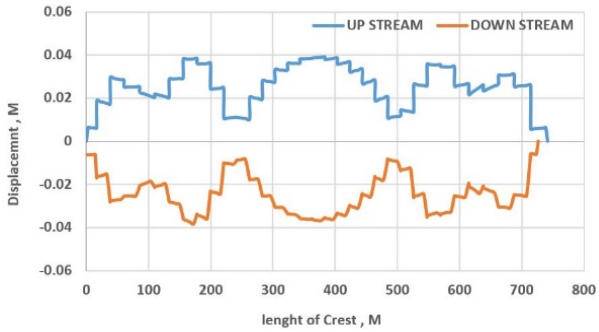

Fig.15 Length of Joint 20 M

Table 5 Max Value of compression stress Along Crown Cantilever, Mpa

Length M	S. Min MPa	Length M	S. Min MPa
15	-8.68898	15	-3.52
17.5	-8.66347	17.5	-3.514
20	-8.69794	20	-3.563
22.5	-8.71546	22.5	-3.513
25	-8.55747	25	-3.51
27.5	-8.73915	27.5	-3.515
30	-8.7289	30	-3.508

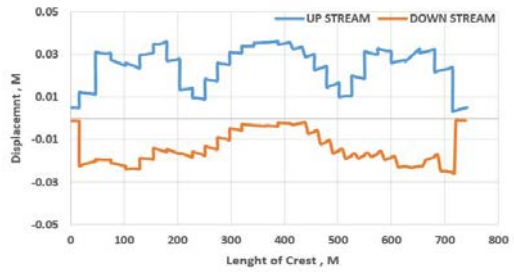

Fig.16 Length of Joint 22.5 M

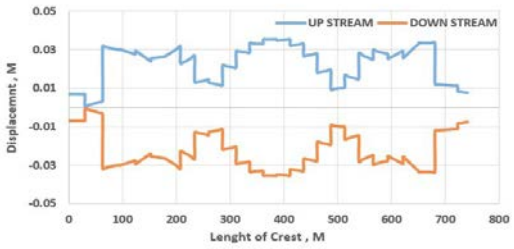

Fig.17 Length of Joint 25 M

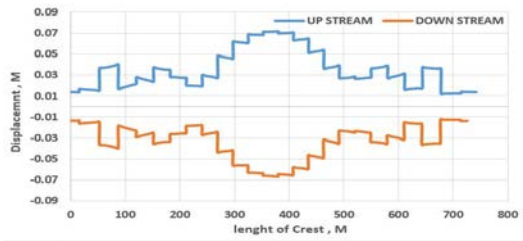

Fig.18 Length of Joint 27.5 M

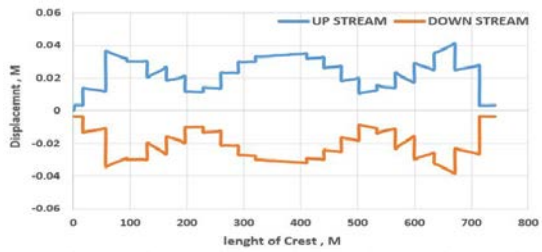

Fig.19 Length of Joint 30 M

The opening of all the contraction joints occurs during the specified earthquake excitation. similar to the other parameter of the dam, length of contraction joints effect on moving the joints to make an opening during an earthquake. max value of joints opening can show in table 5, recorded that the length of contraction joint (15 m, 17,5 m) has the smallest value of joint opening, but the stresses performance of dam with length of joint 15 m and 17,5 m length unpropitious, while the length of contraction joint (20) around 20.27 mm at the face of upstream and 19.53 mm downstream. contraction joint length in between (20 – 22.5) m can rate as the most proper length with regard to joint movement and stresses response.

Table 6 Maximum Joint Opening Upstream /Downstream

Up-stream		Down-stream	
Length M	Joint Opening MM	Length M	Joint Opening MM
15	11.54	15	10.64
17.5	21.66	17.5	18.49
20	20.27	20	19.511
22.5	20.57	22.5	20.93
25	21.53	25	21.53
27.5	23.98	27.5	22.425
30	24.46	30	22.873

11. DISCUSSION

The judgment on the structural performance of the dam relates to a coordinated relationship of stresses, displacements and the values of joint openings. Stresses results showed that the dam's behavior effect relative to distance between two joints. It is noted also, best response of stresses in concrete dam appeared in model have 25 meters joints distance. Results pointed that the tension stress at up-stream face for the above model is less than th models of 15 m, 20 m 22.5 m 27.5 m, 30 m about 19%, 24 %, 19.3 %, 23.2 %, 21 %, 7 % respectively.

Since all stress values are safe, the optimum distance between the contraction joints devises by values of joints openings comparisons. Results show that the best distance between the joints is about 20 m to 22.5 m. In this case there is no need to increase the thickness towards the abutments.

It is pointed that the models with length of joints 25 m ,27.5 m and 30 m have an unfavorable impact of the abutment on both sides. this cause decreases in the It is pointed out that the models with a length of joints 25 m,27.5 m and 30 m have an unfavorable impact of the abutment on both sides. It is necessary to increase the thickness abutments if the designer selects one of the above lengths.

12. CONCLUSION

1. Both stresses and displacement response of the double curvature dam affected by the length of the contraction joints.
2. Modified the design of dam layouts before construction by a updating the geometrical parameters may help to protect the dam during Being subjected to unexpected loads during any period of the dam life cycle.

3. Range of joint length in between 20-22.5 m seems supporting the Hight degree of dam stability.
4. election of the joint length necessity be tied to avoid slandering in both of appearance and structural response of concrete cantilever blocks of an arch dam
5. The results seeming that the dam Under the effect of static and dynamic loads has an immeasurable value of safety factor.

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