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Effect of Contraction Joints on Structural Behavior of Double Curvature Concrete Dam Subject to Dynamic Loading

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Abstract: A double curvature arch dam considers as complex mega structure built for the hydropower or agriculture national goals. Arch dam cost effective is less compared to other types of dams, construction a safe and stable of arch dam depending on intelligent formation of dam layouts. This work conducted to explore the structural behavior of the double curvature arch concrete dam under the variation effect of the distance in between the contraction joints. The dam blocks divided and distributed as seven intervals of the distance between the blocks of the dam as 15,17.5,20,22.5,25, 27.5, and 30 m. Stresses analysis of arch dam conducted to study the effects of these intervals on the structural behavior of double curvature concrete dam when the water in the reservoir at the operation level. Arch dam data input considered the Nonlinearity in both of dam shape and concrete materials properties to evaluate the maximum and minimum principal stresses at the top of the crown cantilever, and the maximum principal stresses along the crest path of the upstream face. Finite element and building information modeling tools (Revit – Abaqus6.13) were considered during the modeling and analysis process. The results show that the dam must be simulated for a specific interval of distance between each two contraction joints are 20 to 22.5 meter and the optimum selection to this interval of contractions joints leads to increase the structural stability status of the arch dam.

Keywords- Double curvature arch dam, Max principal stress, Min principal stress, Modeling.

1. Introduction

The meaning of an arch dam by the International Commission on Large dam (ICLOD) [1] includes all dams that have curved action where the thickness of the base is lower than 0.6 of height (crown cantilever Hight). Arch dam classified according to some main geometrical variables such as constant radius, variable radius, constant angle, multiple arch, cupola, arch gravity, and mixed type. Arch has been formed in canyons with span / height proportion up to 5, or higher, but for a big value of this ratio different patterns of dam perhaps considered, for example, multiple arch dam may select as appropriate form. On great rivers, the arch dam has been built and the site must under environmental impacts like High variation of temperature, great river flood waves, freezing, and thawing. In addition to the economic terms , arch dam is the best choice to reduce construction materials quantities and it is consider the most suitable choice to decrease construction costs economy and honesty are too highly important portions. Usually, the double curvature arch dam will have a tiny volume comparing to other types of dams, practically to gravity dam. Arch dam very strong and durable structure.

Nevertheless, it requires complicated formwork and perfect standard of concrete. In the arch dams, many layouts of the model and architectural formations are prepared within the related data of the work site like water quality, water flow, types of foundations and rock characteristics that are directly related to the final shape of the dam. For this reason, the dam engineers will be under a big challenge to prepare multiple design layouts to select the fit configuration of a dam that will meet with the sit condition. To realize the structural response requirements through their total existence, arch dams, the same as other structures, should be fitly planned, built, and managed. The lifecycle of a dam began with its construction and lasts as long as the existence of the dam consider a hazard to humanity and nature. In general, the existence of a dam viewing the following phases, the first phase while the construction, the second phase at the first time of reservoir fill, last phase through operation, and the abandonment and demolition. even the control of the dam's safety and performance is needed through its all lifetime period, high-quality care, and review is required within the first step, first time of filling of the reservoir and the initial five years of service. The initial behavior necessary for any major structure, the same as a dam, is its honesty. Other conditions should be taken into consideration, as the smallest value of the whole price (construction, performance, and preservation) and the minimum dismissive impact on the environment. Dams should be strong and stable along the whole life to avoid any form of worsening, i.e., both safety demand, and incidents performance demand. Both safety and performance of dams are affected by many factors, namely [3]:

- Structural component, associated with the mechanical properties of the dam structure.
- Hydraulic outcomes, associated with a hydraulic form of appurtenant works, sealing, and drainage systems.
- Operation factor, related to the operating equipment.
- Environmental component, connected with land and water, fauna and flora, community, and making system.

Absolute, Safety, and performance requirements nevermore are guaranteed so that a little anticipation of the occurrence of weakening necessity be accepted. Fundamentally, any weakening or worsen happening while the construction, at the first time of reservoir filling and the first five years of service should be accredited to defect of the design, construction, or service. Any wear out occurring after the first five years of the service should be committed to ageing. Furthermore, there may also happen a deterioration due to the fact of unusual acts. For each dam, the main weakening situations should be determined and thus put a stop to it, by means of the proper layout of the design layouts, a form of construction, rules of operation. Many weakening or deterioration of the dam takes place due to human errors. So, the execution of an adequate quality assurance scenario is required for all the above-mentioned measures. Many studies induced earlier by many researchers about arch dams, its point that the most of studies related with the interface of dam- reservoir – foundation, fracture and crack, evaluation the stability of an existing dam, long term monitoring studies of the dam, etc. less research interest with updating the formation and shape of dam. The main purpose of this work is to consider new concept to improving the dam stability by updating the dam configuration parameters and to consider the shape and proper concrete block distributions as main variables in the design process. This new scenario leads to a finding of an optimum design layout and post- improving the stability of the arch dam at the design stage.

2. Modeling of Dam

Modeling processes of the dam is one of the primary basic steps to examine the structural behavior of the dam, and as it has been indicated in the above paragraphs , so the designer engineers must develops many models, trails adjustments for dimensions, horizontal and vertical radiuses, and angle of convergence of rocks before certifying the basic dimensions of the dam, so it is very necessary to make many set of simulation models within Multiple variables. The Optimal selection of final layout of dam must be valid under the effects of site nature, weather condition, normal and unexpected loads. Simulation of dam consider as a very important step to insure whether the final formation of the dam is appropriate, as well as the simulation have the basic look at the expected structural response of arch dam. In this work, many various sets of models have been generated for arch dams and multiple arch dams considering valley features. They all satisfy the global pattern indicated in figure (1). According to this pattern, two kinds of models can be defined [4,11]:

1. The operations models, defined as a link between the (water, temperature) loads, the dam structural features (hydraulic, thermal, etc.), with the similar responses (forces, expansion, etc.) and final consequences (change of the structural properties or a global failure).
2. The structural models defined as an association among the mechanical outcomes derived from the models of the (forces, strains, etc.), with mechanical characteristics of the dam (deformability, strength, etc.), and based on the structural impacts (displacements, stresses, etc.) and resulting outcome (punctual failures and change of the structural characteristics or a global collapse).

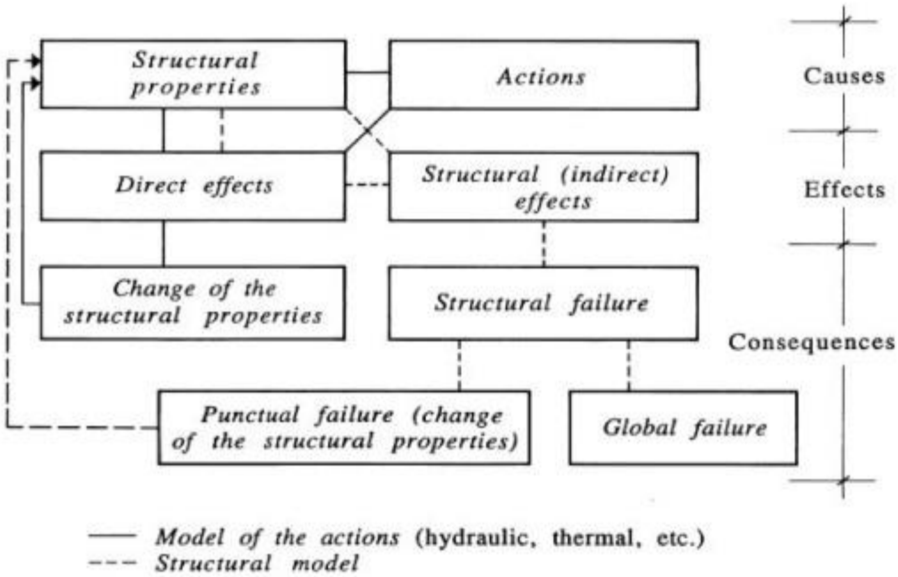

Figure 1. General Pattern of The Dam Models, ICOLD 1994a.

The main objective of this paper is to investigate behavior of double curvature concrete dam under the effect of structural models changes. Arch dams are implemented in the form of adjacent blocks that connect each other by shear connection and filling the space between block by cement materials (grout martials) that the space between these two blocks is called a contraction joints and it has a longitudinal scale ranging min 10 meter to a meter 30 [8] approximately with respect to the height of crown cantilever. The research will consider different intervals of distance for the modeling of contraction joints in this investigation. The distance that that are used in this work as (15-17.5-20-22.5-25-27.5-30) m.

2.1 Numerical Modeling of Double Curvature Arch Dam

Seven models of three-dimension double curvature concrete dam are made by building information modeling tools (Revit) that is consider very wide and flexibility software used for modelling of different types of masses especially when the masses have very complex pattern. In this research arch dam modeled by considering basic dimensions of dam like the length of crest, thickness of crest, thickness of base, radius of both horizontal and vertical curve as well as the length of contraction joints at each step. BIM tools support a full-scale modelling and to linked with multiple FEM software.240m height of double curvature arch dam as shown in figure 2 to figure 4 is selected as an engineering case study and as proposed model for this paper. Total crest length of 775m. The crown cantilever thickness of base 55.74m and 11m at the crest. The material properties for the sound concrete are as follows, concrete mass density was 2400 kg/m3, the modulus of elasticity is 36 GPa and Poisson’s ratio was 0.17. The Cartesian coordinate is functioned with the origin located at the dam base. X, Y, and Z axes are oriented to the right bank of the dam, the downstream and the crest, respectively. The example of dam Cross sectional modeling and the way of divide the body of dam to multiple concrete cantilever block with respect to 27.5 m interval distance in between contraction joints can be shows in figure (2) to figure (5). The meaning of contractions joint distance or spacing intervals in between the concrete block of arch dam explained clearly in Figure (5). By the same way the others models of dam are formed.

Figure 2. Crown cantilever.

Figure 3. Upstream face.

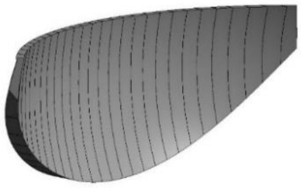

Figure 4. Downstream face.

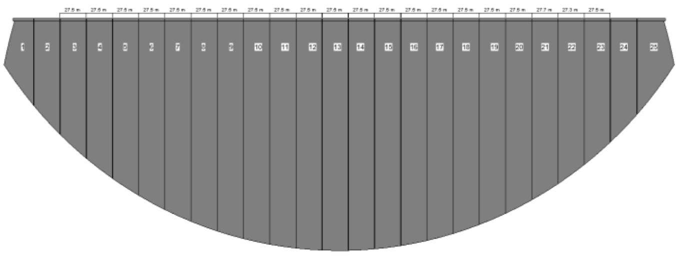

Figure 5. Configuration of dam with 27.5 m distance between joint -25blocks.

2.2 Finite Element Models

Double curvature concrete dam is admired as an independent assemblage of 3D solid elements as mentions in the above paragraph. Arch dam is discretized into 22436 solid 3D elements 8 node and 35874 nodes as shown in fig (6). seven modeling's of a dame with multiple lengths of joint have been analyzed with respect to (15-17.5-20-22.5-25-30) m. The initial strength of the cementation grouting in between the contraction joint is ignored because it does not provide to the joint resistance of the dam. The interaction among the cantilever blocks with each other as hard contact as wells the grouting has tangential behavior and simple sliding action. The interactions between concrete blocks are made as a surface to slave for every two blocks with slim sliding properties.

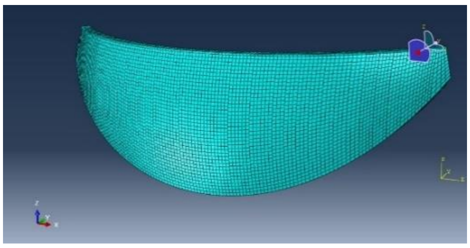

Figure 6. Finite element model with contraction joint.

3. Loading

In general, the primary and secondary loads act on both face of dam and consider a major importance loads for all dam structure, water loads and self-weight are always existing in spite of the fact both loads can vary in magnitude due to external conditions, for example varying in water levels [6].

3.1 Hydrostatic load

Hydrostatic loads controlling mainly on the upstream face and downstream of a double curvature concrete dam, it is an external water pressure varying with a depth of water. water pressure expressed as:

$$pw = \rho w \; g \; \Delta \, h \tag{1}$$

ρw is water density, g the standard gravity, $\Delta \, h$ the water depth (the difference between water level on both side of dam's face).

3.2 Self-weight load

The self-Wight loads is the gravity loads acting as uniform volume load subjected horizontally with respect to body of dam and vertical in the direction of acceleration. From the body of double curvature concrete dam to the foundation. Concrete is main material of dam, even so there will be other parts such as gates and ancillary structure that will have another density and effect the magnitude of the self-Wight load. Its take in consideration and add to the gravity loads as a ratio.

3.3 Sediment load

Since the water of the rivers is not completely pure and always contains large quantities of silt material, especially when the river passing through sedimentary lands, it will certainly be carrying large quantities of silt that will collected cumulatively at upstream of dam and since the silt that depends on the time therefore such a kind of loads almost considered are time dependent. Accumulating sediment will generate load acting on the upstream dam face, Rankin active earth pressure theory taken place to evaluated sediment pressure is described as below equations.

$$ps = \gamma\text{-} \;\; hs \tan^2(\, 45^\wedge{}^\circ - \;\varphi/2 \;) \tag{2}$$

Where, hs is the height of the sediment, φ the friction angle and γ- buoyant unit weight of sediment.

3.4 Hydrodynamic load

When the dam area is exposed to an earthquake, and since the water possesses the kinetic formula, the water in the reservoir is set motion until the reservoir returns to its stability, this will add other forces subjecting to upstream side of the dam and are called hydrodynamic force. H.M. Westergaard has proposed that hydrodynamic force can be seen as force 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 the dam idealizes as monolithic rigid body and the water attached at upstream face of dams, hydrodynamic loads proposed to have parabolic shape. The added mass of water at location (i) is obtained by multiplying the mass density water, ρw by the volume of water tributary to point (i)in the formula of 3.

$$M \; added = \; 0.875 \;\; \rho_w \; A_i \sqrt{H(H - Zi\,)} \tag{3}$$

where H is the water depth, Zi the height above the dam foundation and Ai the tributary surface area at point i. The added masse that explained by Westergaard is then added to the mass of dam at each point of the dam surface described in equation (4).

$$M \; total, = M \; dam + M \; added \tag{4}$$

3.5 Unusual loads

The exceptional loads are the loads that are have a low probability to occur like earthquake load effects, in case of seismic disturbance the loads will be generated due to inertia of dam and the retained water.

horizontal and vertical accelerations subjecting to dam along the earthquake duration which both have considered in this paper. This paper considering global and famous earthquake date to investigate the behavior of double curvature arch dam, the real time – acceleration of imperial valley earthquake is subjected at the base of the models. It had magnitude of 6.9 and a maximum perceived intensity of maximum accelerations with respect to 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. Simultaneous of actions at the upstream, cross-stream and vertical ground motion components are considered. (PGA) peak ground acceleration of the earthquake motion is 0.3119 g in X direction, 0.21g in Y direction and 0.205 in Z direction. Three components of the earthquake motion are showing in Fig. 7.

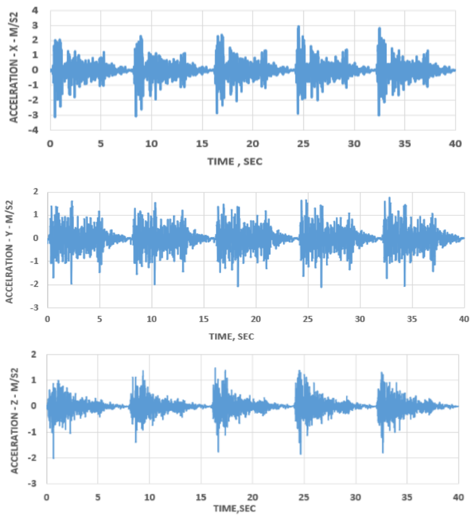

Figure 7. Input of earthquake motion amplitude, PEER-strong motion data base.

4. Application of Boundary Condition

To become of rigid body motion, it should be imposing boundary conditions along the area of the dam-foundation interface. For example, fixed boundary condition clamped boundary condition and simply supported condition, etc. Boundary conditions either define as the loads that act on the structure (force or Neumann boundary conditions) or explain the way in which the structure is supported (displacement boundary conditions). Both kinds of boundary conditions connected to clarify the structural model of the dam to be most familiar to the real structural condition, Either, to decrease the model size by substituting the 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 which applied held: fixed - fixed (Ux, Uy, Uy and Rot x, Rot y, Rot z) are restraint at the nodes along the bottom area of the dam and at both sides of abutments.

5. Principal stresses

Since S is a symmetrical matrix it can be diagonalized, 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 [7,8,9]. 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

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the principal stresses $\sigma 1$, $\sigma 2$ and $\sigma 3$ in the principal directions: n1, n2 and n3. The principal stresses are usually classified by their size where:

$$\sigma 3 \leq \sigma 2 \leq \sigma 1 \quad (5)$$

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, $\sigma 1$, is used to find the areas of tensile stress and the minimal principal stress, $\sigma 3$, is used to find areas of compressive stress.

6. Structural Dampening

Since it is infeasible to define the coefficients of the damping matrix from the structure dimension, Structural portion size and the damping of structural materials utilized particularized numerical values for the modal damping ratios [10]. Modal damping ratios include all energy-dissipating mechanisms and they are sufficient for analysis of systems with classical damping. by considering modal analysis for the models of double curvature concrete dam model to estimate the mode frequencies that will guide to getting the damping coefficient for the entire full-scale body of dam by considering results of first and second mode that may be selected. Modal analysis of the dam structure was performed in Abaqus to find the modal frequencies.γ , β evaluated from any two mode as below:

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

Where, ε = 0.05, ωi frequency of first mode ωj frequency of second mode selected. The frequencies $\omega 1$=8.3774rad/s and $\omega 5$=16.143rad/s were chosen for calculation of the Rayleigh damping, using a damping ratio of ε = 5%, a reasonable estimate of the dynamic response of concrete hydraulic structures, resulted in damping factors γ= 0.55152595 and β= 0.00203912.

7. Results and Discussion

The structural evaluation for the double curvature arch dam mainly depends on the stresses analysis because there are no big issues related with seepage and uplift or overtopping comparing to gravity dam. The only over stresses is consider as a very important issue for the behavior evaluation process of the arch dam. Nonlinear analysis has been employed for seven model of double curvature concrete model with respect to multiplane distance of contraction joint when the dam under the effect of full hydrostatic loads 230 m of water level up stream, downstream hydrostatic loads, silt load, seismic load and hydrodynamic. During the analysis by using FEM tools software package of Abaqus 6.13, Maximum and Minimum stress results for the node at top point of crown cantilever shown in figure (8) and stresses along the crest path on upstream face shown in figure (9) will be discussed in this paper.

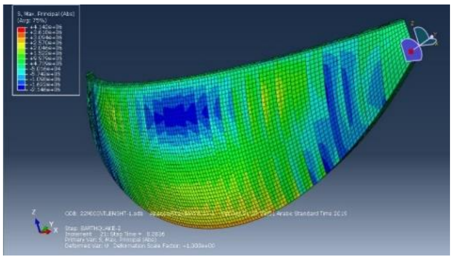

Figure 8. 3D Modeling Dam.

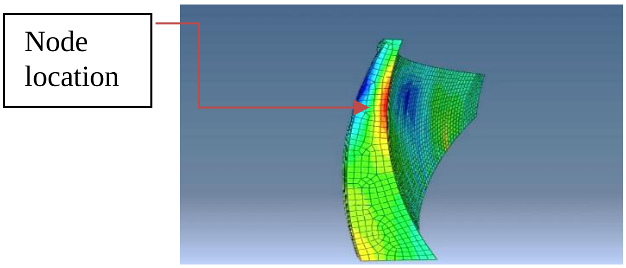

Figure 9. Location of Node.

7.1 Maximum Principal Stress (Nodal Value - Top of Crown Cantilever)

Maximum principal stresses are usually referring to the tensile stresses. In this section, the nodal stress history developed at top of crown cantilever on the side upstream reviewed below. Results of stresses for seven models of double curvature concrete dam with respect to the variation of distance in between two joints of contraction joint can be noticed in figure (10) to figure (16).

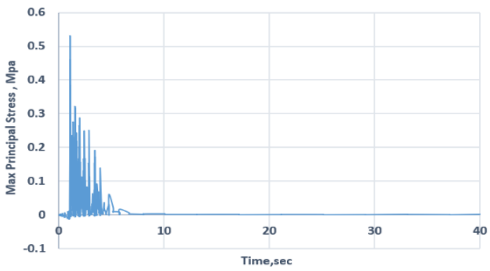

Figure 10. S. Max Joint distance -15 m.

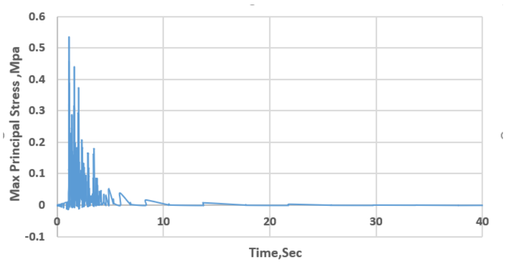

Figure 11. S. Max Joint distance -17.5m.

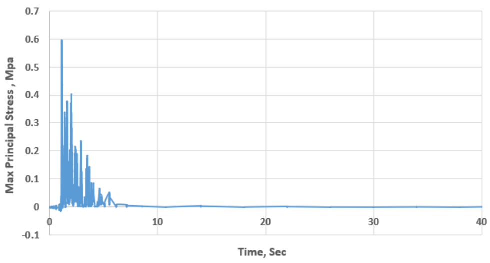

Figure 12. S. Max Joint distance - 20 m.

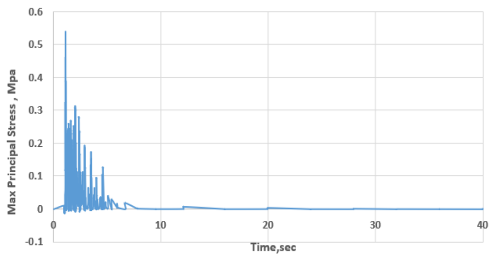

Figure 13. S. Max Joint distance - 22.5 m.

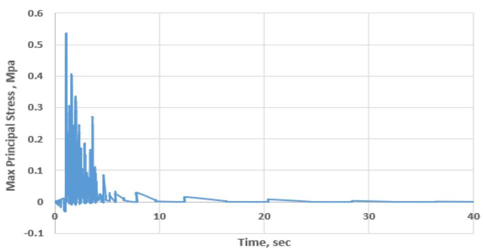

Figure 14. S. Max Joint distance - 25m.

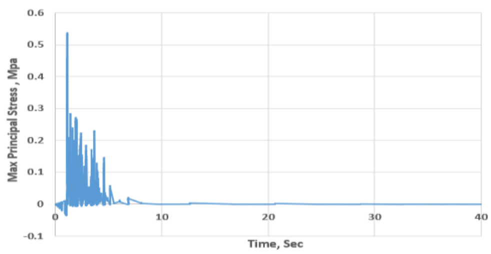

Figure 15. S. Max Joint distance - 27.5 m.

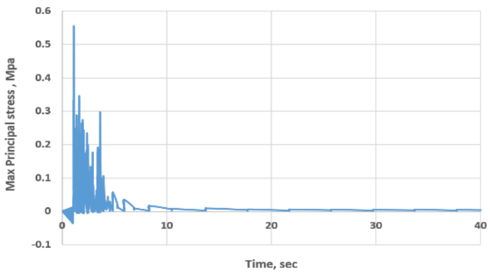

Figure 16. S. Max Joint distance – 30 m.

It is pointed that the maximum principal stresses of arch dam for model with joint ditance interval of 15 m is less by (0.043 %, 10.89 %, 0.399 %, 0.146 %, 0.543 %, 3.448 %) than the models of (17.5m,20m ,22.5m ,25m ,27.5m, 30m) length of contraction joints respectively.

7.2 Minimum Principal Stress (Nodal Value - Top of Crown Cantilever)

For same location of node at the top of crown cantilever, compression stress can be evaluated by investigated of minimum principal stresses. Results show the compression stresses for the seven models as shown in the figure (17) to figure (23):

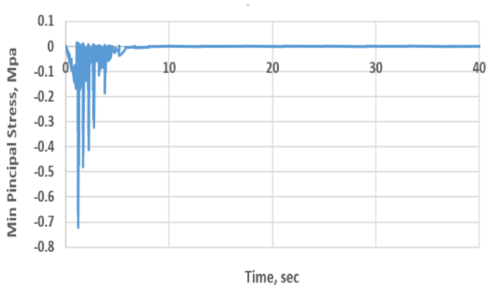

Figure 17. S. Min joint distance -15 m.

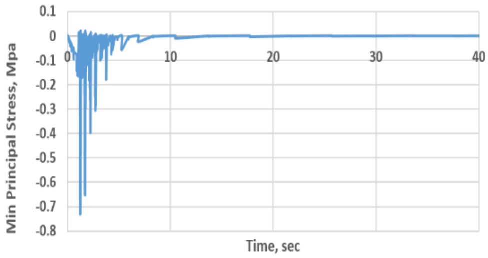

Figure 18. S. Min joint distance -17.5 m.

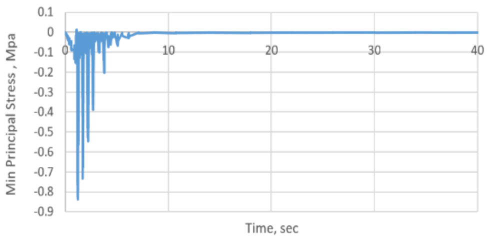

Figure 19. S. Min joint distance - 20 m.

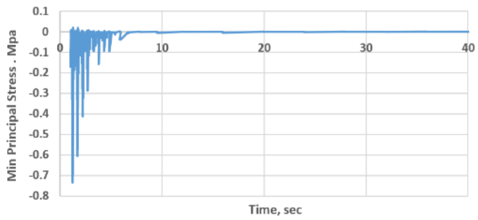

Figure 20. S. Min joint distance - 22.5 m.

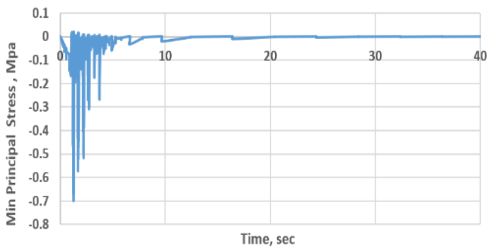

Figure 21. S. Min joint distance - 25m.

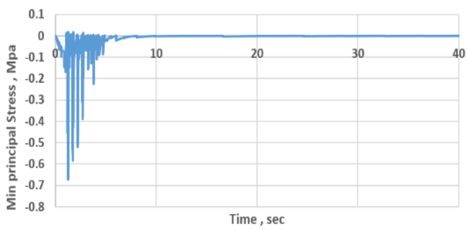

Figure 22. S. Min joint distance - 27.5m.

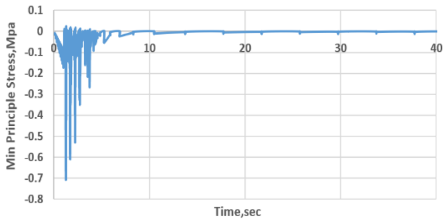

Figure 23. S. Min joint distance - 30 m.

It is noted a sound convergence for compression stress results. Generally, concrete has a high potential to withstand pressure, as opposed to tensile stress.

7.3 Maximum Principal Stress (along the crest path Values - up stream face)

Maximum principal stress along the crest at the side of upstream also considered in this paper under the same loads condition, it can easy to see the effects of changing the length of contraction joint on the behavior of whole body of dam. It is common knowledge that the area of fastening of rocks is often critical and may possess large tensile values, and gradually increase the thickness from the middle of the width of the dam to the area of abutment. In this case, thickness of the dam can be increased gradually to the area of contact with the rocks at both abutments. This paper shows that the tensile stresses along the crest may affect length of contraction joint, some of length show homogenous behavior and the others models have stress disturbance along the nodes of crest path as shown in figure 24 to figure 30.

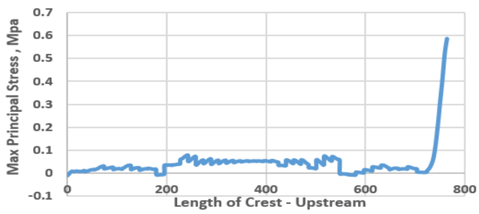

Figure 24. S. Max joint distance -15 m.

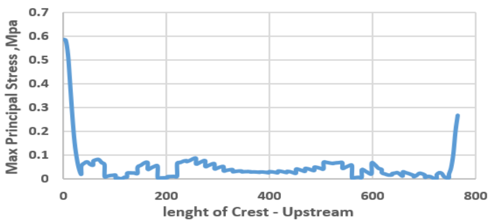

Figure 25. S. Max joint distance -17.5 m.

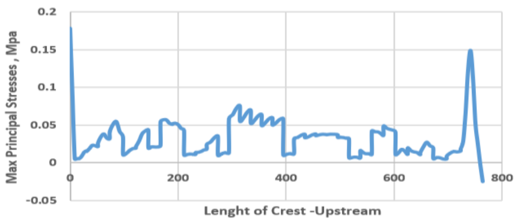

Figure 26. S. Max joint distance – 20 m.

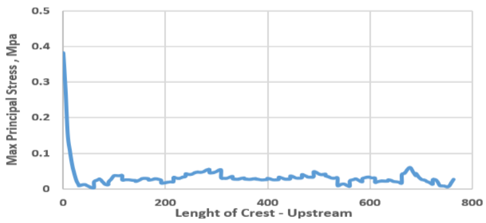

Figure 27. S. Max joint distance- 22.5 m.

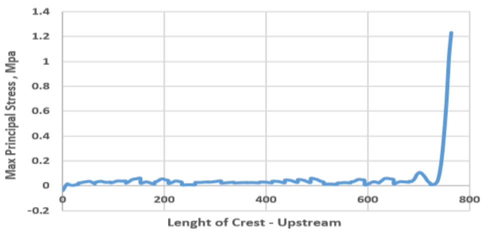

Figure 28. S. Max joint distance - 25 m.

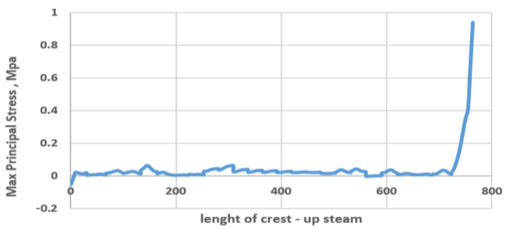

Figure 29. S. Max joint distance - 27.5m.

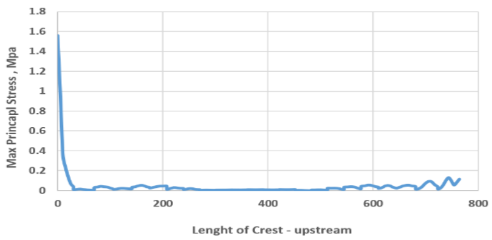

Figure 30. S. Max joint distance -30 m.

It is pointed highly tensile stresses at the abutments zone in all models. The model of dam with 20 meters of distance between joints have tensile stress less than the (15 m, 17.5 m, 22.5 m ,25 m, 27.5 m, 30 m) by (70.288%, 70.83 %, 0.53%,85.8%, 88,58 %) respectively. the results show that the optimum distance between two contraction joints in between the range of (20- 22.5) m.

8. Conclusions

Based on the above results for double curvature concrete dam simulations, the points below can be Elicitation:

- It was observed that the double curvature concrete dam's behavior affected by the distance in between the contraction joints under the influence of usual and unusual loads.
- It is recorded that the optimum distance between two contractions joints range from 20 m to 22.5 m according to the results of tension and compression stresses.
- It was observed that the safety factor under the influence of the worst case of stress along the crest path approximately equal to 2.7. While the likely safety factor value must be not less than 3 for Stabil and safe dam.
- Increase the dam thickness towards the abutments may lead to avoiding the high value of tensile stresses.
- It’s possible to achieve ~~a~~ positive structural response of dam by little modification for vertical radius of arch dam.
- The direction of the maximum seismic amplitude directly influenced the structural response of the arch dam. The results indicated to this matter. This fact is because most of the stress values are concentrated on both sides of the dam's body at abutments as well as to the thrust loads from the reservoir acted in the plane of the arch of the dam body.

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