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EFFECT OF CREST SHAPE ON THE STRUCTURAL PERFORMANCE OF THE DOUBLE CURVATURE CONCRETE DAM

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ABSTRACT: Arch dam stability is one of the main engineering challenges that must be met in the early stages of investigations and design of the dam. The highest degree of stability can be achieved if the dam 's structure formed in best layouts and the free ends of the dam body, defined by the crest, restricts especially if the dam is affected seismically. This research study falls under the auspices of the second phase of concrete dam construction, i.e. design stage. Nonlinear finite element analysis is performed in order to investigate the structural behaviors of the four models of double curvature concrete arch dam. Three-dimensional models of arch dams are prepared to utilizing Revit, the building information modeling software. Subsequently, the four models are linked to the finite element's tools package of Abaqus 6.13 for the purposes of discretization and structural analyses. The models have the same mechanical properties and basic dimensions and differ only in the form and physical appearance of a crest (crest shape). Amplified of crest shape caused a slight movement of the dam center of the mass to be optimally positioned, and thus the new center of mass supports the stability of the dam. The varying effects of crest configurations on the whole dam structure response were discovered according to the results of maximum and minimum principal stresses along the crown cantilever path as well as to the displacements response along the crest path of the arch dam. Strengthening or amplified crest dimensions could decrease arch dam thickness for a certain value and can reduce the response of the displacement to about 30 percent. The results indicated a reduction in the undesired movement between the adjacent cantilevers at the contraction joint zone, so a marvelous response was remarked in both of triangle upward edges crest and triangle downward edges crest models.

Keywords: Arch Dam, Finite Element, Path, Center of mass, Crest amplified.

1. INTRODUCTION

Arch dams are considered large and strategically important projects enabling countries to achieve a degree of significant economic, agricultural and hydropower goals [1, 8]. Arch dams are built on the major river tracks as such locations have demonstrated great merit and susceptibility to bear the forces acting on the upstream face of the dam. Besides, arch dam has a high operational efficiency compared to other dam types [13, 14]. On the other hand, the choice of dam construction location became suitable for high altitude to meet the hydropower energy requirements.Dam is considered as a shell structure that is arched both longitudinally and transversely. Water pressure is shifted to the abutments by the arch action, the primary load in the arch dam is compressive. Since concrete has high compressive strength, the cross section of an arch dam can be significantly smaller than that of a concrete gravity dam. Due to the very large thrust loads, the stability of the abutments is critical to the success of an arch dam [13]. There is a major difference within the load-bearing behaviour of structures and bridges on the one side, and dams on the other. Under ordinary conditions, buildings and bridges have to carry primarily perpendicular loads due to the dead load of the structures and some secondary live loads. In the case of dams, water in reservoir load is acting on the vertical upstream face horizontally [13]. This unique condition requires high level of expertise and accuracy during the dam construction along with precise planning, designing and construction stages. One of the most significant steps of the construction of the dam is the design stage. Engineering companies must conduct numerous high-detailed studies to properly select the final shape parameters of the dam. While the designers are conducting modernization and optimization works in order to add stability features to raise the capacity of the dam by using shape variables. A wide range of studies have been done in other fields with an aim to increase the efficiency of large projects by improving the shape or physical appearance of the particular parts. For example, the wind turbines' blades, aerodynamic design of cars, aircrafts, or express trains illustrate the use of the geometrical configurations as a principal parameter to increase the efficiency of said projects. This research focuses on the formal modernization of the arch dams' components to raise its efficiency, or reduce the thickness of cross sections. Dam layouts are rolled by physical appurtenance dimensions as a length of crest, crown cantilever height, base thickness, crest thickness and radius of horizontal and vertical curvature. Since the dam configuration depends on its morphological properties, any change in the dam apparent shape causes a change in the dam's response. This relation is underlined as limitation criteria such as thickness/height ratio, and length/height ratio that we may use to classify dam as thin or thick etc. The aim of this research is to update configuration of the dam free ends, which is known as the crest. Four models of arch dam are utilized to monitor the structural response of with respect to crest formal updates [1, 7, 8 ,and 14].

2. THE EFFECT OF SHAPE PARAMETER

In numerical simulation processes for any product or structural member, section formation is one of the most important points of the designer attentions. The designer aims at ensuring efficiency, quality, durability and time of implementation for each section or structural member that he try to select it to be inside the construction in real [7,11]. Accordingly, it is noted that science is particularly interested in geometrical appearance and characteristics of all engineering sections since it is possible to find a simple change in physical properties of any sections leads to change its response. With regard to dams' construction, a number of engineering determinants is closely related to the shape and configuration of a dam, as mentioned above, the limitations including the proportion of span to height and thickness to height. The other important parameter is optimum distance between cantilever's blocks [1]. With a high degree of confidence, we may argue that a suitable combination of basic dimensions of the dam in terms of base thickness, crest physical properties as well as the radius of the vertical and horizontal curvature of double curvature arch dam and other shape parameters can help to increase the capacity of arch dam. Further, it adds to stability under the effects of the lateral loads during the service period. Basic dimensions are selected after conducting many analytical layouts. Results of analytical layouts can show the suitability the basic dimensions only. The process of updating physical appearance of dam dimensions is undertaken with the assumption that the foundations of the dams are of an ideal condition. Dam engineers face a great challenge during the planning period to achieve high efficiency structure and economic dimensions. The cost-effectiveness and reliability are additional extremely vital factors in the selection of a dam. Usually, arch dams have significantly lower mass compared to other dam types, especially to gravity dams, and are very stable and durable structures. Nevertheless, the downsides may include expensive formworks and the requirement for a high-quality concrete and a more complicated arrangement. It appears that the utilization of roller-compacted concrete in the construction of arch dams will lead to an optimum balance between economics and reliability [7].

3. THE MODELLING OF A DAM

Numerical simulation of a dam project is the first action of safety evaluation. For this reason, the dam depends on how the simulation is formed. Several kinds of models have been developed for the arch and multiple arch dams. Thus, two models for the analysis of the double curvature dam are available. The first model that explains the relationship between impact (water, temperature, etc.), structural characteristics (hydraulic, thermal, etc.) and related effects (forces, development, etc.) and possible outcomes (structural characteristics changes, or global failures). The second model is structural and describes the connection between the mechanical effects produced by the models of action (forces, strains, etc.) mechanical properties (deformation, strength ...), the related structural outcomes (displacements and stresses etc.) and other subsequent impacts (punctual failures, structural change or a global failure)[2, 6, 7,and 14].

3.1 The Structural Modelling Considerations

Numerical modelling and solutions of double curvature dams concerning analytical roles of the finite element method have the same assumption that may be used in other structures, such as three-dimension modelling, mesh requirements, loads matrix, and boundary condition. However, there is a certain set of points to adhere to during researching an arch dam project which can be outlined as follows [3 , 5]:

a) The dam foundations interface assuming must be precise to support the loads with no structural weakness or stability difficulties.
b) The effect of contractions joints and pre-existing of crack that may happen due to any construction senility.
c) Mesh density depends on stress intensity at holes or corners, in this case, the mesh must be so fine. if the idea is to examine sliding or rocking it is possible to consider course mesh.

The arch dam must be as thin as possible, and this concept must meet the requirement of hydrodynamic and reservoir couple effect. This means that the mass of concrete that accelerated in the gravity dam is large than the concrete accelerates with the arch dam as the acceleration of water on of the most important analytical factor of double curvature dam. The modelling of the reservoir can be modelled by the elements with no shear's strength. Westergaard added mass theory is suitable for modelling the hydrodynamic effect on the upstream face of the dam [2, 3, 4, and 5] . It is understood that the Westergaard pressure distribution was derived from a rigid body displacement of a vertical 3-dimensional upstream face.

3.2 Finite Element Modelling

Four models of the double curvature concrete dam with multiple shapes of crest are portrayed as an independent assemblage of 3D solid elements, as shown in figure (1) .

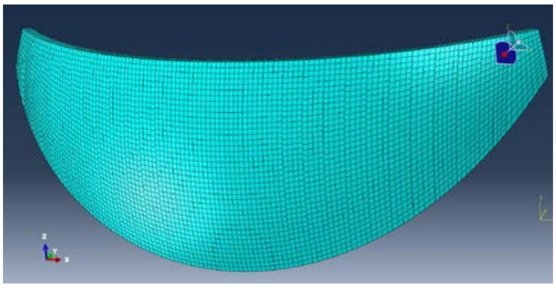

Fig.1 Finite element modeling

The dam is discretized into 22436 , 22649, 21836, and 23234 of Solid 3D elements for the models of flat edge crest, Triangle upward edge crest, Triangle downward edge crest and rectangular edges of crest respectively [6, 7, 10, 12, and 15]. 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 behaviour with a simple sliding movement had been defining regarding this issue as shown in figure (2).

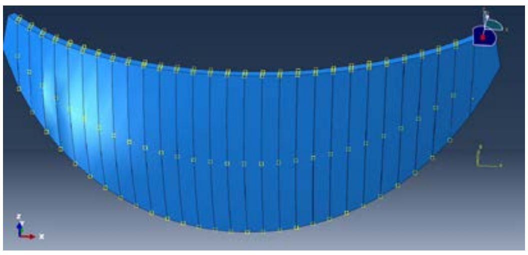

Fig.2 Cantilever block contact

Phyaicl properties of concrete and the charactrestic of case studey explain in Table (1).

Table 1 Basic Data Elastic Properties of the case study

Item	Value	Remarks
Total Crest Length	775m	left to right abutments
Crown cantilever height	242 m	From foundation elev. to crest elev.
Crest Thickness	11 m	Us/Ds projection 3.5 m,2.9 height
Crest Elevation	1205m	Above sea level
Contraction joints	22.5m	Optimum distance
Base of Dam Elevation	956m	Above sea level
Base Thickness	55.74m	Ideal fixed to foundation
Concrete Modules of Elasticity	36 GPa	Elastic properties
Poisson ratio	0.17	Elastic properties
Density of concrete	2400 kg/m3	N-A

The nonlinearity of concrete material was taken into account in this work as shown in figure (3) and figure (4) .

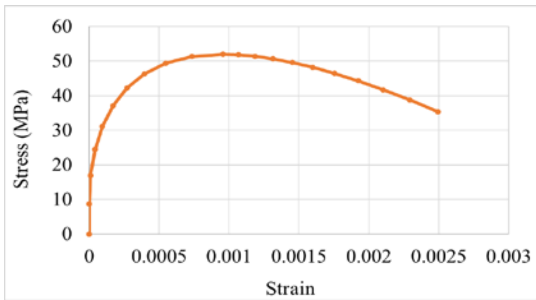

Fig.3 Concrete behavior - compression

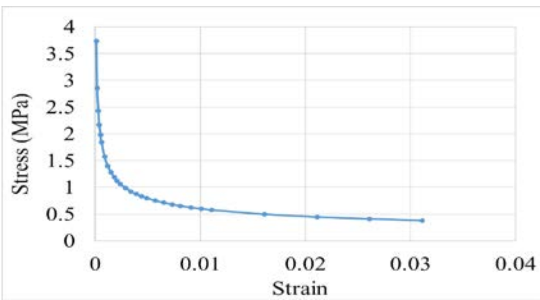

Fig.4 Concrete behavior - tension

Up-stream and down-stream faces for double curvature of dam were modeled as shown in figure (5) and figure (6) . Twinty nine contraction joints of 22.5 meters as an interval between each two joints and 30 concrete cantilever blocks were modelled in the simulation of dam as shown in Fig. (7). 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.

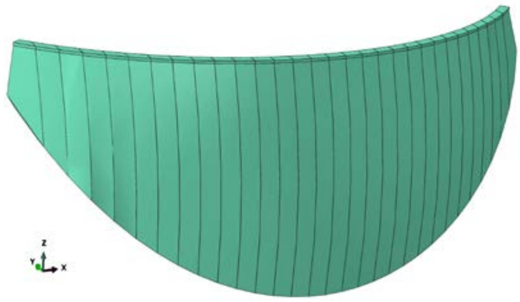

Fig.5 Up-stream face

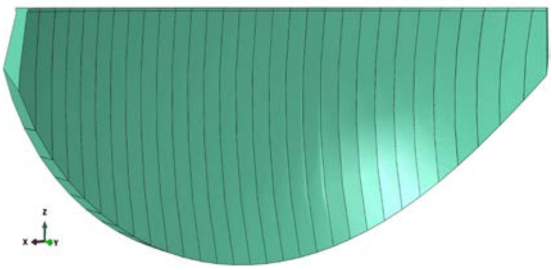

Fig.6 Down-stream face

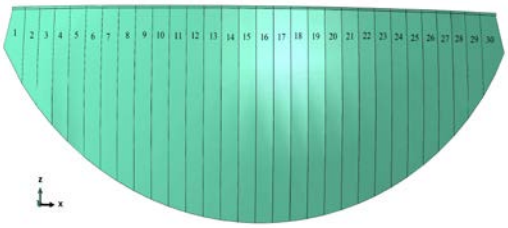

Fig.7 Contraction joints and number of cantilevers block

The main objective of this paper is to investigate the crest ampilify on the structural behavior of four models of double curvature concrete dam under the effect of static and dynamic loads. It is commonly known that dams are implemented in the form of adjacent cantilevers that connect each other by shear connection and filling the space between cantilevers by grout materials. Updating the physical appearance of the crest stems from assumption that the strengthening of the toper part of dam changed the mass distribution along the canliver blocks .Crest amplify helps to increase the stability of dam with respect to stress and displacement response. Four models double curvature concrete arch dam can be shown in figure (8) to figure (11).

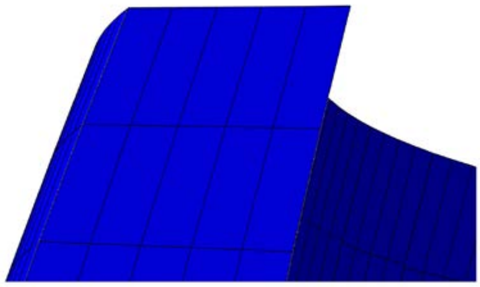

Fig.8 Flat edge crest

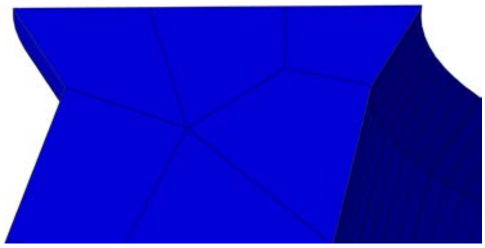

Fig. 9 Triangle upward crest

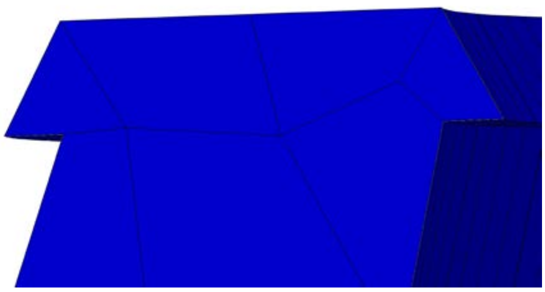

Fig.10 Triangle downward edge crest

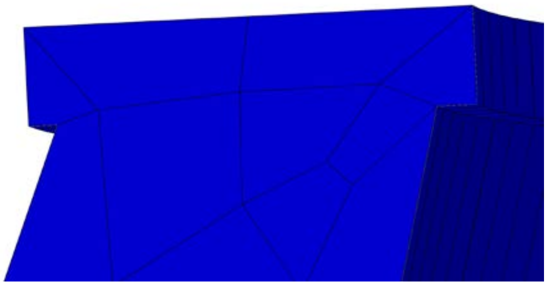

Fig.11 Rectangular edge crest

4. DAMPING PROPERTIES

The degree of structural amplification of the ground motion at the base of the structure is limited by structural damping. therefore, damping is ability of the structure system to dissipate the energy of earth quake ground shaking. Since the structure response is inversely proportional to damping's. the more damping a structure possesses, the sooner it will stop vibrating – which of course is highly desirable from the standpoint of earthquake performance. 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 we assess the modes shape and oscillations that guide us to find the damping coefficient $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$. Water pressure on the face of upstream can express eq.1 by considering full-scale of modal analysis for the dam to then, by regarding the results of the first and second mode. Frequencies can be calculated from any two modes, as shown in Table 2, and damping parameters can evaluate as mention in eq. 1.

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

Where, $\boldsymbol{\varepsilon}$ = 0.05, $\boldsymbol{\omega i}$ frequency of first mode $\boldsymbol{\omega j}$ frequency of second mode selected. The frequencies $\boldsymbol{\omega}1$= 8.3774 rad/s and $\boldsymbol{\omega}5$ = 16.143 rad/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 2 Modal analysis results

mode. no	eigenvalue rad/time	frequency cyclic/ time	frequency cyclic/ 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

5. STATIC AND DYNAMIC LOADS

The dam is exposed to static and dynamic loads. Hydrostatic load and gravity load (self-weight) are always considered 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 [2, 3 ,7 and 11].

5.1 Hydrostatic Loads

In general, hydrostatic load is acting on the upstream and downstream face of the dam. It is considered as external water pressure. The hydrostatic load is a function of water height eq. (2) along with the operation live cycle of the

$$\boldsymbol{pw} = \boldsymbol{\rho w}\ \boldsymbol{g}\ \Delta\,\boldsymbol{h} \qquad (2)$$

Where $\boldsymbol{\rho w}$ density of water, g the standard gravity, and $\Delta\,\boldsymbol{h}$ water depth.

5.2 Gravity Load

The self-weight load is the gravity load acting on the dam along the horizontal direction. The main material of a concrete dam is concrete, however, there will be some parts such as gates and ancillary structures that will have another density and affect the magnitude of the self-weight load [3, 5, and 12].

5.3 Hydrodynamic Loads

Earthquake acceleration causes motion of water in the reservoir, resulting hydrodynamic forces exerted on the upstream face. As proposed by H.M. Westergaard [4, 8, 11, and 14], the hydrodynamic force can be seen as equivalent to inertia forces of volume of water attach and moving back and forth with dam while the rest of the reservoir water remain inactive. For the purposes of analysis of the dam he idealizes rigid monolithic with upstream face of body of water attached to the dams proposed to have parabolic shape as mention in eq. (3). The added mass of water at location (i) is obtained by multiplying the mass density water, $\boldsymbol{\rho w}$ by the volume of water tributary to point i in the formula.

$$\mathbf{M}\ \boldsymbol{added} = \mathbf{0.875}\ \boldsymbol{\rho_w}\ \boldsymbol{A_i}\sqrt{\boldsymbol{H}(\boldsymbol{H}-\boldsymbol{Zi})} \quad (3)$$

Where H is the water depth, Zi the height above the dam base and Ai the tributary surface area at point i. eq. (4) explain the Westergaard added mass is then added together with the mass of the dam at each point of the dam surface.

$$M\ total = M\ dam + M\ added \quad (4)$$

Gravity dam water mass is equivalent of 33% of total mass while it's about 59% of total mass for gravity mass.

5.4 Silt Loads

At the upstream face of the dam, accumulating sediment will generate load acting on the upstream dam face, the sediment pressure is described with Rankin active earth pressure theory as in eq. (5).

$$ps = \gamma\text{-}\ hs \tan^2(45^{\wedge\circ} - \varphi/2) \quad (5)$$

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].

5.5 Earthquake Loading

There is a necessity of investigating the behavior of arch dam under the maximum regional earthquake so there are no stresses, calculation the stain, or other parameters. Seismic study is conducted in order to assess whether or not damage will be significant enough to compromise the dam's capacity to resist the static and post-earthquake forces. What is of importance is not the peak stress, but rather explained offsets and cracking. If it can be shown that with reasonably conservative assumptions concerning earthquake-induced damage, the post-earthquake static loads can be resisted, then earthquake loading does not need to be directly considered. [7, 13, 14 and 15]. Three-dimension acceleration amplitudes of Imperial Valley earthquake of 1940 consider in this study. It had a moment magnitude of 6.9 and a maximum perceived intensity of X (Extreme) on the Mercalli intensity scale. The peak ground acceleration (PGA) of the earthquake motion is 0.3119g in X direction, 0.21g in Y direction and 0.205 in Z direction [12, 16]. The three-dimensional of time acceleration components of the earthquake motion are showing below in Figure (12) consider as acceleration boundary condition.

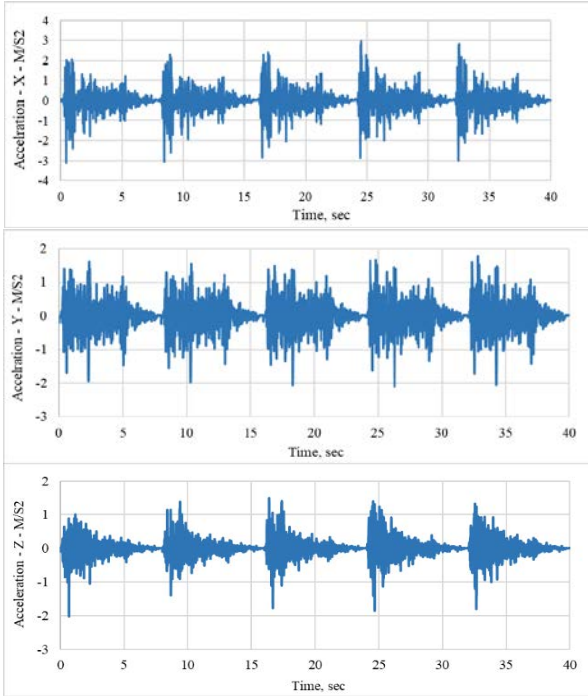

Fig.12 Acceleration – Amplitude components [16]

The above histories show heterogeneous amplitude of acceleration for x-y-z direction. Maximum acceleration recorded towards the x axis. This type of earthquake is considered to be of high intensity and dangerous to huge constructions of dams.

6. THE CRITERIA OF STRUCTURAL RESPONSE

As all structures and during the loads applied on the concrete body of dam, deformations and movements developed as normal response for the loading. Deformations and movements variation of dam sensing are caused by displacement and stress responses. On the other hand, openings between the joints are one of the most important sensor responses for dams. The tensile strength of an arch dam is regularly limited by the capacity of horizontal lift joints, vertical contraction joints, and pre-existing cracks in concrete block to resist tension [2, 5]. For this reason, the accurate determination of the tensile strength of the intact concrete is typically not necessary. It is recognized that principal axis tension may exist. Reasonable estimates of tensile strength as a function of (Fc) include in eq. (6):

$$\begin{gathered} \boldsymbol{ft = 10\%\,FC} \\ \boldsymbol{ft = 7.5 \times (Fc)^{\frac{1}{2}}\ \ ACI\ 318} \\ \boldsymbol{ft = 1.7 \times (Fc)^{\frac{2}{3}}\ \ Rapheal - static} \\ \boldsymbol{ft = 2.6 \times (Fc)^{\frac{2}{3}}\ \ Rapheal\ - seismic\ actual} \\ \boldsymbol{ft = 3.4\ \times (Fc)^{\frac{2}{3}}\ Rapheal - seismic\ apparent} \end{gathered} \quad (6)$$

As these assumptions of tensile strength is formed without attention for a special fault or weakness in the blocks concrete of cantilever, such as the lift joints, and because the tensile strength across such joints may be significantly less than in the homogenous material, it would be judicious to assume the tensile strength for the lift joints is less than that for the homogenous concrete. The actual tensile strength across the badly constructed lift joints of some older dams could be even drastically lower than that for the homogeneous concrete. A compressive axial load is applied to mold cylinders, or cores until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load achieved during the test by the cross-sectional area of the specimen. The results of this test method are used as a basis for quality control of concrete. Both the tensile and compressive strength limitations use structural criteria that may give positive or negative indication under the effect of multiple loads.

7. BOUNDARY CONDITION

Three dimensional models are developed for double curvature concrete dam with respected to the massless foundation concepts that may add to be equivalent to the behavior of ideal foundation. The body of the dam was defined as being fixed bound by a strong and ideal foundation fixed boundary condition already define in this paper with no displacement at the direction of X, Y, Z and there is no rotation (X, Y, Z) [2, 5].

8. VALIDATION OF ABAQUS

Seismic analysis of Ertan dam located in china was consider as a basic model for this verification. The maximum tensile stress on upstream face evaluated by EACD-3D-2008 along the dam cantilevers is 3.98 Mpa on the face of upstream and 3.56 Mpa on the face of downstream. Abaqus shows that the maximum tensile stress at the face of upstream equal to 3.816 Mpa while 3.495 Mpa downstream for the zone of crown cantilever and 4.25Mpa near the abutment. The percentage of the stresses results Discrepancy approximately 4.12% for upstream 1.8% for downstream. The minor differences of results are because of fine mesh of Abaqus model.

9. RESULTS AND DISCUSSION

This research shows the results along two major paths. The first path along the crest of the dam from the left to the right abutment and the second path along the crown cantilever. Both of maximum and minimum principal stresses are discussed along the first path for all models. The other comparison shows the displacement response along with the crest and crown cantilever baths and the contraction joints opening values.

9.1 Max/Min Principal Stress Along the Crown Cantilever

It is always indicated that tensile stresses have another notation as maximum principal stress regarding to the resulting of the stress components. Maximum principal stress along the crown cantilever of double curvature concrete dam along upstream face will take in the paper comparison considerations. It will be clear to find the effect of strengthening of crest on the structural stress response in both of Figures 13, and 14.

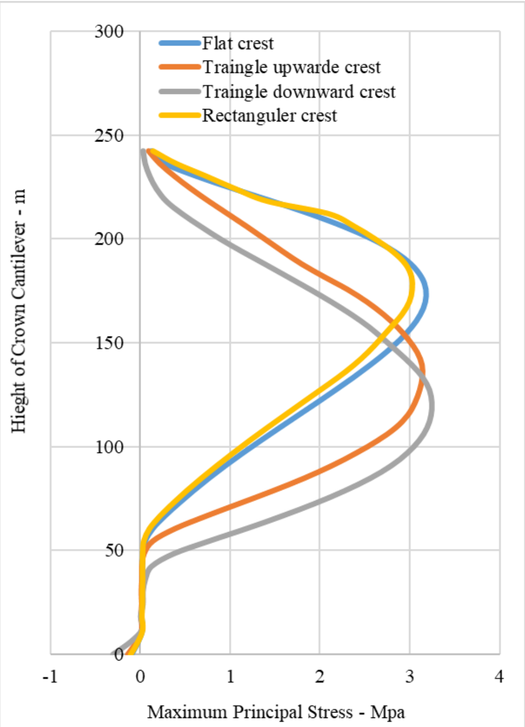

Fig.13 Crown Cantilever - Upstream

Tensile stresses are displayed as positive signs value. In this paper, the stress path consisting of a series of nodes along the crown of cantilever. The stresses results of the four models of the arch dam showed different results in terms of response. The triangle upward edge crest model showed more homogeneous results as well. The structural behavior of the dam was more agile as the highest tensile values appeared in the larger part of the longitudinal section. This behavior can be seen clearly at a height of 0.45 H and 0.9 H as shown in Figure 14. Convergence was observed in the stress results of the three models and an increase in the carrying capacity of the triangle downward edge crest model as in Figure 14.

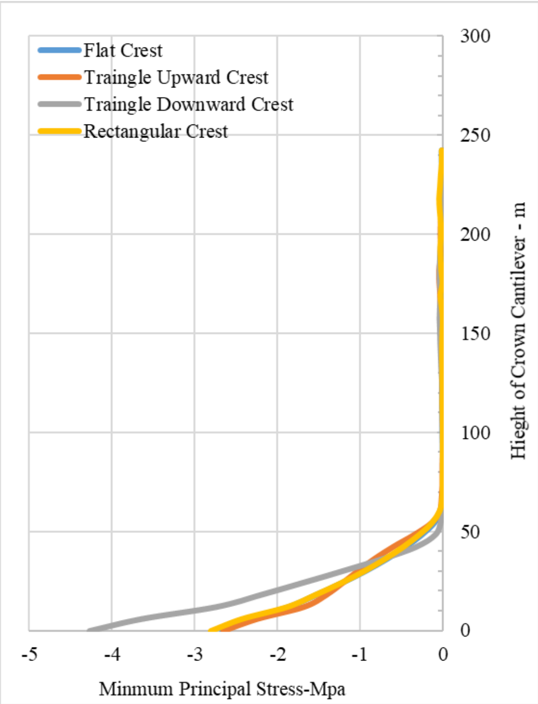

Fig.14 Crown cantilever – Upstream

9.2 Displacement Along the Crest

The second determinant of the structural comparison of the dams is the displacement variable along the major crest and crown cantilever paths. All the desired displacements and joint openings of the dam may appear along the crest path under the effect of unusual loading. A path consisting of a chain of nodes was taken along the crest and the action of displacement was pursued between the concrete blocks. Whether the dam is made up of a group of blocks, all with free ends that can move and displace during the excitement of the load. Figures 15 and 16 show the upstream and downstream displacement response of the four models of the dam.

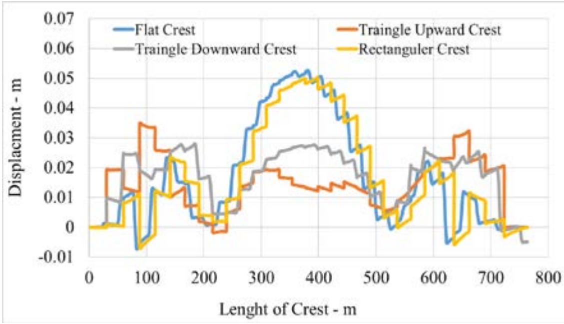

Fig.15 Displacement– Upstream

The dam response shows that the displacement is ideal for the triangle upward edge crest model in the mid of crown cantilever of the dam. It is pointed that the displacement of dam with triangle upward edge crest is less around 53 %, 75 %, 74 % from the model of triangle downward edge crest, flat and rectangular model of crest respectively. The response varies near the abutments. It is noted that the triangle upward edge crest model has a higher displacement response than the others models. This condition can be overcome by increasing the thickness towards the abutments. The displacement response appears to effect of crest shape on the structural response of dam.

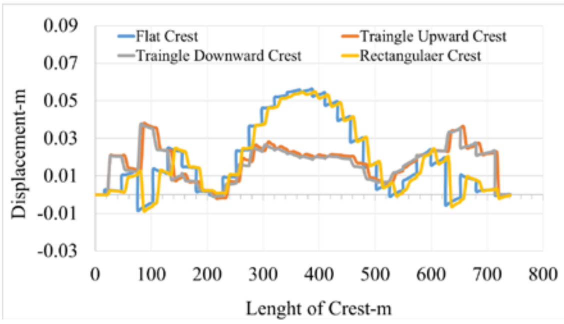

Fig.16 Displacement– Downstream

At the downstream face It is pointed that the displacement response for both of and downward model of dam Showcased behavior comparing with flat and rectangular crest shape model. The model with triangle downward model displacement response less by 32.622%, 0.72%, 31.44 % than the models of (flat, triangle upward, rectangular) crest shape as shown in figure 16.

9.3 Displacement Along the Crown Cantilever

The other indicator of stability to be evaluated is a movement along the crown cantilever. In general, there are three components of the displacement in (x, y, z) direction along this path. The four models differ in configurations of the crest shape. The displacement response along the crown cantilever block can show in Figures 17, 18, and 19. The results show that the displacement response in the direction of X for the model with triangle downward less by (77.671 %, 29.771 %, 77.689 %) than the flat, triangle upward, rectangular models of arch dam respectively. While the displacement in the yy and zz direction for the same model less by (54.72 %, 3.357 %, 53.43%) and (50.82%, 1.77 %, 33.83%) than the flat, triangle upward, rectangular models of arch dam respectively. Any unlikely movement of the series of aligned concrete cantilever blocks cause opening in the joints. These openings cause a break of the grouting materials existing in between the contraction joints, and therefore there is a great possibility for water to drain from the other side.

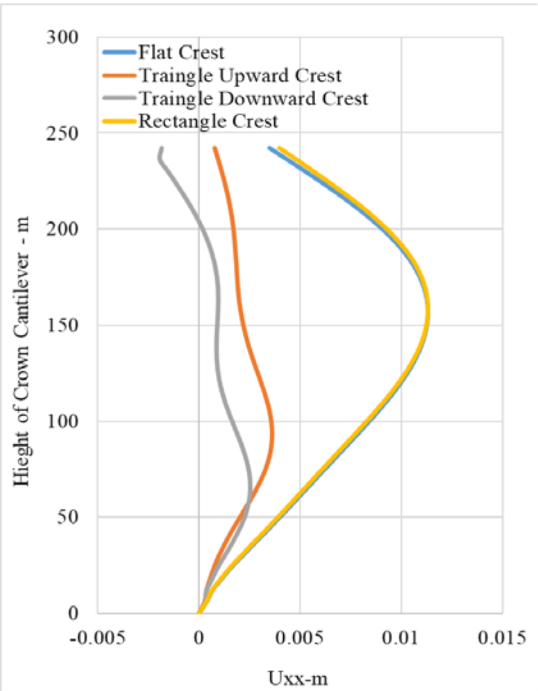

Fig.17 Displacement – X direction

Table (3) shows the values of the maximum openings between the joints in both of abutment and crown cantilever at the upstream face of dam.

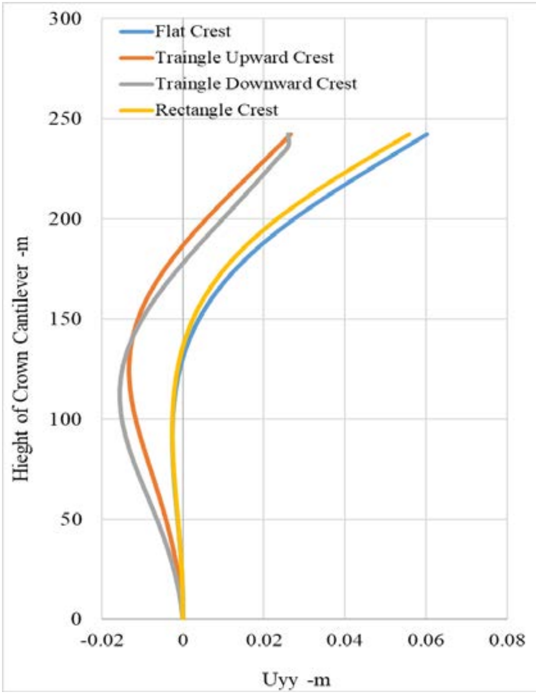

Fig.18 Displacement - Y direction

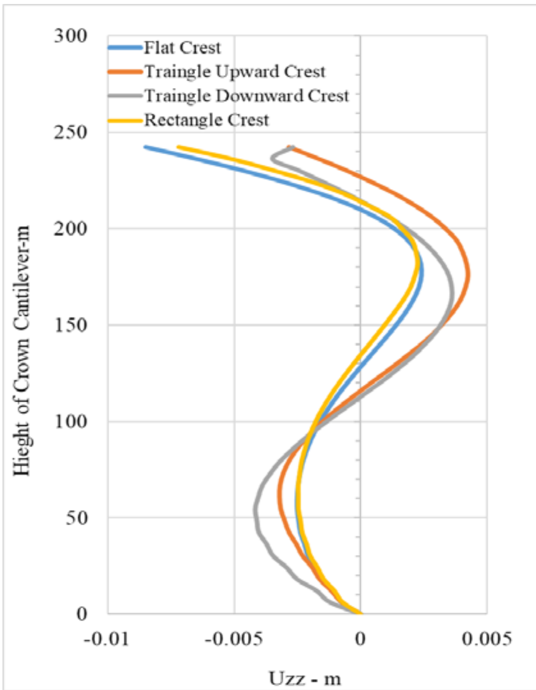

Fig.19 Displacement – Z direction

Table 3 Maximum Joints Opening –Upstream, mm

zone	flat	triangle upward	triangle downward	rectangular
Abutment	14.5	22.88	16.45	12.89
crown	0.7	0.15	0.2	0.47

Triangle upward crest model shows maximum opening at the abutment zone and minimum value at mid of dam. The results pointed that the triangle upward crest model has joint opening higher about 36,27 %, 28.10 %, 43.66 % than the flat, triangle downward and rectangular crest shape respectively. at the mid of dam, the value of joint opening less about 78 %, 25 %, 68 % than flat, triangle downward and rectangular crest shape respectively. follows from the foregoing determination that the triangle upward edge crest model of crest has an optimum performance if the thickness increases gradually towards the abutments. Table 4 explain the response of the joint at the downstream face.

Table 4 Maximum Joints Opening–Downstream, mm

zone	flat	triangle upward	triangle downward	rectangular
Abutment	21.51	25.20	25.61	20.99
crown	1.33	0.79	0.89	1.149

The results of the openings between the joints towards the downstream are greater than the father Stream, due to the effects of damping in the water dam reservoir. The model of triangle upward edge crest shape has joint opening larger about 14.84 %, 18. 33 % the models of flat and rectangular crest shape and less than 1.6 % triangle downward edge near the abutment. Triangle upward edge crest model shows minimum value of joint opening than the flat, triangle downward edge, rectangular crest shape models about 40.6 %, 11.23 %, 31.24 % respectively at mid of the dam.

10. CONCLUSIONS

Research results lead to the following points:

1. It is possible to improve the structural capacity of a double curvature concrete arch by updating cantilever block layouts and updating the physical appearance of the dam structural components.
2. Increasing mass at the free end of the cantilever blocks is like a damper and movement restricted, which decreases displacement of dam during earthquake.
3. The Change of crest shape lead to change in location of the dam center of mass in such amount to be assigned in a new place, These assists to a raise the capacity of the dam.
4. Displacement response for the model with triangle downward edge of crest is less by 32.622%, 0.72%, 31.44 % than the models of (flat, triangle upward, rectangular) edges crest shape respectively.
5. It is pointed that the displacement of dam with triangle upward edge crest is less around 53 %, 75 %, 74 % from the model of triangle downward edge crest, flat and rectangular model of crest respectively.
6. Increasing the crest stiffness help to decrease the failure in terms of the joint opening in both faces of the dam.
7. Stability of double curvature concrete dam increase if the dam configuration used the triangle upward edge crest and triangle downward edge crest shape in the modeling of the dam structure.
8. The above points suggest that the triangle upward edge crest and triangle downward edge crest models of the dam can be viewed as optimum models in terms of structural response according to stability indications.

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