

# Static Analysis and Safety Evaluation of an Arch Dam

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**ABSTRACT:** For over five thousand years, as evident in the cradles of civilization, dams have played an important role in regulating water flow to cater to the needs of irrigation. They endow important quantities of water that are absolutely crucial for human consumption and industries, in addition to irrigation. Dams form key structures for harnessing hydroelectric power, with all its advantages over other sources of large energy generation, as well as for control of floods. They have also played a vital role in taming some of the largest rivers on earth, in many cases at points upstream from cities and developed valleys. Their number, height, economic and social importance has increased exponentially over the last decades, including their cost. The huge capital outlay required for dam construction coupled with the devastating effect it can have on life and property in case of failure, is a cause of great concern. Thus, it is essential to ensure the safety of these structures in the design, pre- and post-construction stages. This has become a necessity to ensure the safety of people as the damages caused by the failure of dam can be catastrophic. Here an attempt is made to develop a Finite Element Model of an arch dam, which can be used to analyse stresses and deformations that would occur in the dam.

**KEYWORDS:** arch dam, finite element analysis, stresses.

## I. INTRODUCTION

Finite Element Method (FEM) is an essential and powerful tool for solving structural problems not only in the marine field but also in the design of most industrial products and even in non-structural fields. FEM can be used for a wide variety of problems in linear and non-linear solid mechanics, dynamics, and submarines structural stability problems, in accordance with the development of computer technology and its popularization. The conventional method in solving stress and deformation problems is an analytical one using theories of beams, columns and plates, etc. Hence, its application is restricted to most simple structures and loads.

A dam is a barrier that impounds water or underground streams. Dams generally serve the primary purpose of retaining water, while other structures such as floodgates or levees (also known as dikes) are used to manage or prevent water flow into specific land regions. Hydropower and pumped-storage hydroelectricity are often used in conjunction with dams to generate electricity. In history, different types of arch dams were developed due to the prevailing ability of doing the structural engineering calculation of the geometry of the dam. As for example constant radius or constant angle arch dams allow a simplified structural analysis, which is basically explained in this chapter, they represent the initial arch dam types. Due to the fact that this simple geometry arch dams are hardly appropriate to asymmetric topography, further geometry development was necessary. By the use of the Finite Element Method, it has become possible to do a structural analysis for complex geometries and hence, double curved arch dams arise.

Constant radius arch dam the geometry of the constant radius arch dams is realized with arches of equal radius, regarding the upstream face of the dam. Using a constant radius at any height of the dam causes the upstream face to be

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vertical. Considering the linear increasing water pressure by depth, the dam's thickness is increasing linear by depth too. Therefore, the vertical sections of a constant radius arch dam are similar to the shape of a gravity dam. Constant angle arch dam the geometry of a constant angle arch dams is characterized by equal angles of the surfaces of the abutment. By transferring forces, having the same angle, to the ground, the thickness of the arch dam and therefore the volume can be reduced. Although the volume is decreasing when using that arch dam type, effort is increasing, caused by curved upstream surfaces and thereby resulting additional amount of formwork. To realize a constant angle arch dam, the opening angle should lie between  $100^\circ$  and  $130^\circ$ .

Double curved arch dams feature horizontal as well as vertical arches. Therefore, the geometry of double curved arch dams is the most suitable concerning load transfer and volume reduction and can be fitted to nearly every asymmetric valley shape. The vertical sections are commonly realized with circles, whereas the horizontal arches are often realized with conic sections, basket-handle arches or logarithmic helices. Despite the fact that double curvature dams have the most convenient structural behaviour, the effort, regarding design and construction is enormous. Without using modern calculation methods, such as the Finite Element Method, it would be hardly possible to investigate strains, displacements and stresses for such a complex geometry.

## II. RELATED WORKS

Anil K. Chopra [1] identified the limitations of the traditional design procedures, the factors that should be considered in the dynamic analysis are discussed, and procedures for earthquake response history analysis are summarized. The current state of knowledge about earthquake response analysis of concrete arch dams, and the application of this information to the earthquake-resistant design of new dams and to the seismic safety evaluation of existing dams. The limitations of the traditional design procedures are identified, the factors that should be considered in dynamic analysis was also discussed. In this the procedure for earthquake response history analysis was also summarized. In this the application of linear analysis procedures to seismic design and safety evaluation of dams was also discussed. In this the prediction of the performance of concrete dams during earthquake is one of the more complex and challenging problems in structural dynamics. In order to produce safe and economical designs of concrete dams, the most reliable techniques consider in this paper should be concerned. The EACD-3D computer program mentioned in this paper was used in recent seismic safety evaluation of dams.

Feng,Wei *et.al* [2] did a comparative study on the performance and ultimate bearing capacity of dams. A set of safety factors was presented in this paper with regard to dam heel cracks and the ultimate bearing capacity of a high arch dam. The curtain safety factor  $k_1$ , the structural mutation safety factor  $k_2$ , and the ultimate safety factor  $k_3$ . The factor  $k_1$  reflects the curtain safety at the dam heel,  $k_2$  describes the structural mutation stage for the adjustment of the multiple arch-cantilever system, and  $k_3$  reflects the ultimate bearing capacity of the entire dam structure. A comparative study on the performance and ultimate bearing capacity of dams is performed to give a more reasonable evaluation criterion of safety factors. The curtain safety factor  $k_1$  was verified by the constructed arch dam Kölnbrein according to its real working performance. The other safety factors are then justified by numerical simulations and geo mechanical model tests of the Xiaowan arch dam. Moreover, a comparative study is carried out among the Kölnbrein, Ertan, and Xiaowan arch dams to give a more reasonable evaluation of high dams. Finally, an evaluation criterion of the safety factors is suggested: when  $k_1$  is greater than 1.05, the grouting curtain should be safe, and when  $k_2$  and  $k_3$  are greater than 2.0 and 3.0, respectively, the dam-foundation system should have a relatively high ultimate safety. Finite element modeling of arch dams is also presented in this paper.

Gao LIN, Zhiqiang HU and Shichun CHI [3] did feasibility study of vibration control systems applied to massive structure, a 292m high arch dam was carried out. Seismic analyses of the arch dam including nonlinear behavior of joint movements demonstrate, that installation of viscoelastic dampers in the contraction joints can reduce the maximum tensile stresses at major part of the dam to a great extent. Effectiveness of mounting mild steel dampers in the contraction joints was also studied. Dynamic analyses taking into account the nonlinear behaviour of joint movements reveal that installation of energy dissipating devices in the contraction joints is effective to reduce the seismic response of the dam. With regard to the efficiency of energy dissipation, frequency dependent visco elastic

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dampers are better than displacement dependent mild steel dampers. Installation of control devices in the arch direction of the joints is more rational than installation of such devices in the radial direction. Masterarbeit [4] developed a software based calculation of the 3D coordinates of double curved arch dams and the additional processing of these coordinates using Finite Element software. To calculate these 3D coordinates, a program based on Visual Basic for Applications, which is a Microsoft Excel tool, was developed. By varying the input parameters and using different calculation methods, it is possible to determine the geometry of double curved arch dams and modify it for optimization purposes.

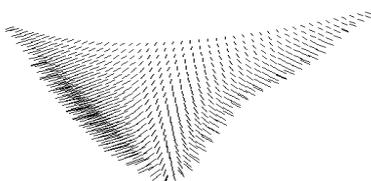
Engineering guidelines for the evaluation of hydropower projects by Federal Energy Regulatory Commission (FERC) deals with the static and dynamic analysis of dams. Further it includes few case histories of different dam failures. Scott L. Jones and Guy S. Lund [5], done stability evaluation on Myponga Dam, a concrete arch dam owned and operated by the South Australia Water Corporation (SA Water), is located on the Myponga River. The linear finite element analysis was used to perform a stability evaluation of Myponga Dam for the usual (full supply level), unusual (inflow design flood), and extreme (maximum design earthquake) loading conditions. The finite element computer program ANSYS was used to perform analyses of Myponga Dam to determine the maximum stresses and deformations in the dam due to the assumed loading 10 conditions. Based on the initial results, understanding that the joints in the foundation would not carry significant tension, adjustments were made to the material properties in the linear model to better simulate conditions and understand the response of the dam. The updated results from the modified model indicated that the stresses in the dam were less than the allowable strength of the concrete.

### III. MODELING

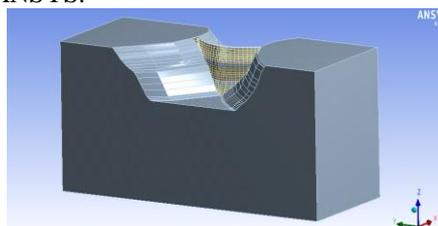
The actual structure also consists of horizontal inspection galleries and vertical shafts connecting them. These are not considered in modeling of the dam. The dam section actually consists of steel reinforcements to support the inspection galleries and shafts which are neglected since in this project, inspection galleries and shafts are not considered. A program was developed with the help of analytical definitions of the dam. On inputting the size of the mesh, the coordinates of the dam were obtained in AutoCAD. The Auto CAD was in the form of .dwg in which lines were drawn. These coordinates were joined using lines and then areas in AutoCAD. These were then formed into volumes and converted into solid model. The solid model of the dam was imported to ANSYS, over there foundation where created then meshing and analysis were conducted. The solid model of the dam and foundation was developed in ANSYS, where modeling was completed. The material properties of the dam were assigned and meshing was done. The meshing provided here was tetrahedron mesh. The mesh provided here was fine mesh for the accurate result. The element used was SOLID185. This element is used for 3-D modeling of solid structure. It is defined by eight nodes having three degrees of freedom at each node. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials.

### IV. EXPERIMENTAL RESULTS

Figures shows the modelling and results obtained from analysis. Figure 1 shows the coordinates of the dam in AutoCAD. Figure 2 shows the arch dam modelled in ANSYS.



(1)



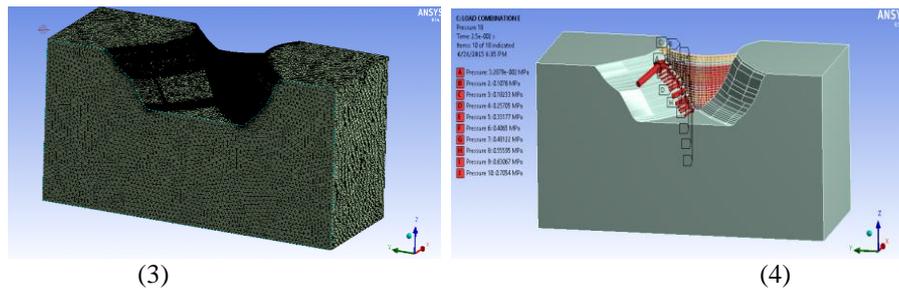
(2)

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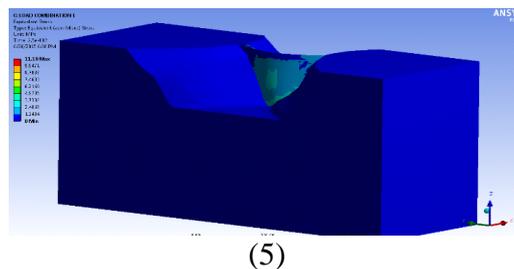
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Figure 3 shows the meshed model in ANSYS. Figure 4 shows the load combination in ANSYS.



Limiting stress as per 'Engineering guidelines' by FERC is the concrete compressive strength reduced by the prescribed factor of safety. It can be observed that the maximum compressive stress values for the proposed model have not exceeded the limiting values as per FERC. Figure 5 shows the stress resultant value which does not exceed the norms of FERC.



## V. CONCLUSION

The analytical definitions of arch dam were obtained with the help of a PYTHON program. The dam was modeled using AutoCAD, and imported to ANSYS, where analysis was done for various load combinations. The dam and foundation was modeled in finite element analysis software. The stresses corresponding to each load combination were checked with the permissible limits as per FERC guidelines. The results of analysis of model do not disclose any areas of overstress. Therefore, it is justified to state that the actual stresses is expected to be within the established criteria, under existing loading conditions.

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