# Fluid Structure Interaction of Arch Dam on Full Reservoir Level under Seismic Loading

Manikandan R 1 , R.Jayashiri 1 , R.Indumathi 1 , J.Archana 1

Dhirajlal Gandhi College of Technology, Salem, Tamil Nadu, India

**Abstract:** The Fluid Structure Interaction (FSI) is the important role for the seismic analysis and the design of hydraulic structures. The fluid structure interaction occurs due to the exchange of energy between moving fluid and solid structures. In this study the Finite Element Model is analyzed with impounded water considering appropriate boundary conditions between the water & the upstream face of the dam .The fluid on the upstream side is considered to be incompressible, inviscous, and irrotational. Here the effect of fluid compressibility is analyzed by the use of COMSOL Multiphysics Software. The impact of water pressure on the upstream face of the dam is obtained by the computation of stress and displacements for the arch dam considering compression of fluid element. The fluid flow in the dam is described by the in compressible Navier-Stokes equations for 2D Dam model and the Solid Mechanics interface features for stress analysis and for solving the displacements.

**Keywords:** Fluid Structure Interaction, acoustic elements, hydrodynamic pressure, fluid element

## 1. Introduction

The analysis of seismic, stability and deformation of a dam system is an important factor in the field of earthquake engineering, Bering in mind the recent earthquake events, this commission has proposed to evaluate in the seismic behavior of a large concrete arch dam, taking into account the fluid-structure interaction of double curvature interaction

In this paper the solution obtained using COMSOL Multiphysics is presented in details, outlining the main potentialities of the software in solving the acoustic pressure and acoustic structure interaction for corresponding impound water on the upstream side of the dam.

## 2. The Finite Element model

The FEM model provided with fine mesh of the dam-reservoir system and the foundation rock domains have been extended towards the upstream direction to evaluate properly how the wave pressures move within the water basin.

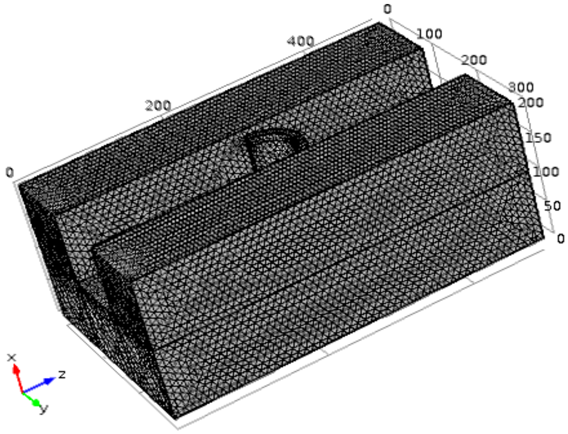

**Figure 1**.Double curvature Arch Dam Model.

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## 3. Analysing Model Aspects

Linear elastic constitutive models have been assigned to either the dam or the foundation rock. The physical-mechanical properties are summarized in Table 1.

**Table 1:** Concrete and rock properties

| Domain | Density [kg/m3] | Poisson ratio | Young modulus [MPa] |
|---|---|---|---|
| Dam Body | 2300 | 0.33 | 25000 |
| Rock Strata | 2600 | 0.25 | 60000 |

The reservoir has been discretized by means of acoustic finite elements whose properties are reported in Table 2.

**Table 2:** Water properties

| Domain | Density [kg/m3] | Speed of sound in water[m/s] | Bulk modulus [MPa] |
|---|---|---|---|
| Reservoir | 1000 | 1500 | 2200 |

-The computation of hydrodynamic pressures as added masses was proposed by Westerguard.

-The fluid elements are solid elements to which the characteristics of the water are applied. The incompressibility or the water as well as the null shear resistance are introduced with a Poisson number equal with 0.5 or close to this value for the finite element programs. The bulk modulus of the water is K=2200 MPa.

-The acoustic elements are used to model the fluid behavior of the air. They have no shear and tension resistance and they transmit only pressure. With assignment of the water bulk modulus they model the water behavior very good. Numerous boundary conditions can be assigned to the acoustic elements, which model natural phenomena such as wave absorption at the far end of the reservoir, sloshing of the free surface. For the acoustic elements no special numerical care has to be taken except for assigning the boundary conditions.

-One of the main concerns regarding the numerical dynamic analysis of arch dams is the proper modeling of the fluid-structure interaction between the dam and the impounded water .There are several approaches to this, which enables accounting for the hydrodynamic pressures on the upstream face of the dam with different precision and, respectively, with different computing effort.

-This work investigates the impact of the hydrodynamic approach opted for on the computed stresses and displacements of an example 90m high double curvature arch dam. It is shown that, for this particular benchmark problem, it is important to consider the compressibility of water.

## 4. Analysing Methods

### -The Fluid structure interaction

The fluid flow in the channel is described by the incompressible Navier-Stokes equations for the velocity field, u = (u, v), and the pressure, p, in the spatial (deformed) moving coordinate system

$$\rho(\partial u/\partial t)\ \nabla\ [-pI+\eta(\nabla u+(\nabla u)^{T})]+\rho((u-u_{m})\nabla)u=F$$

$$-\nabla\cdot u=0$$

In these equations, I denotes the unit diagonal matrix and F is the volume force affecting the fluid. Assume that no gravitation or other volume forces affect the fluid, so that F = 0. The coordinate system velocity is $u_m = (u_m, v_m)$.

### The Acoustic-Solid Interaction, Frequency Domain interface

This model provides a general demonstration of an acoustic fluid phenomenon in 3D that is coupled to a solid object. The object's walls are impacted by the acoustic pressure. The model calculates the frequency response from the solid and then feeds this information back to the acoustics domain so that it can analyze the wave pattern

The Acoustic-Solid Interaction, Frequency Domain interface's default Pressure Acoustics Model feature models harmonic sound waves in the water domain by means of the Helmholtz equation for sound pressure

Here the acoustic pressure is a harmonic quantity, p = p0eiωt, and p is the pressure (N/m2), ρ0 is the density (kg/m3), ω is the angular frequency (rad/s), and c is the speed of sound (m/s).

### The Solid Mechanics

The Solid Mechanics interface defines the quantities and features for stress analysis and general linear and nonlinear solid mechanics, solving for the displacements.

The Linear Elastic Material node is the default material model. Other material models are generic hyper elastic and linear viscoelastic material models.

In addition, the elastic material model can be extended with plasticity, thermal expansion, damping, and initial stress and strain features. The description of elastic materials in the module includes isotropic, orthotropic, and fully anisotropic

## 5. Analysing Results

The model where the solid interface is regarded as a hard wall. In this model, turn off the structural analysis of the Dam body and the surface to an acoustic hard wall with the boundary condition up to the U/S of the dam.

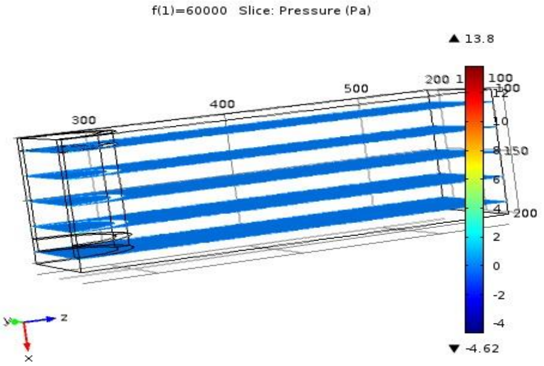


**Figure 2**. Slice pressure from the Dam body up to U/S end.

Figure 2 displays the sound pressure as a slice plot. It is clear from which direction the sound wave propagates into the domain. The values of the deformation are very small, but the acceleration is large enough to have an impact on the sound waves.

Figure 3 shows the acoustic pressure field of the Dam body up to the U/S of the dam with 10 slices pressure distribution.

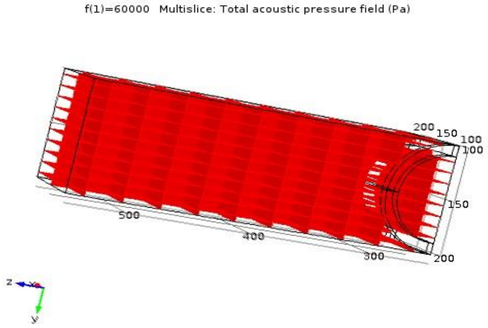


**Figure 3**. Total acoustic pressure field.

In this example, eigenfrequencies of an acoustic enclosure are computed and the modeling domain and the boundary conditions applied for the Helmholtz equation and the mixed formulation, respectively. The computed eigenfrequencies are now seen to deviate slightly from the analytical values. The reason for this discrepancy can be seen from the computed mode shapes where the close-up plot reveals a boundary layer in the vicinity of the solid-acoustic boundary. Thus the boundary introduces a no-slip condition, which is not modeled by the ordinary Helmholtz equation. This no-slip condition cannot be circumvented in the present topology optimization model but its effect is diminished with mesh-refinement. It may, however, be discussed whether the idealized Helmholtz equation actually represents acoustic vibrations accurately. In reality, the physical boundary condition is no-slip and therefore there will always be a small boundary layer in an exact model of an acoustic problem.

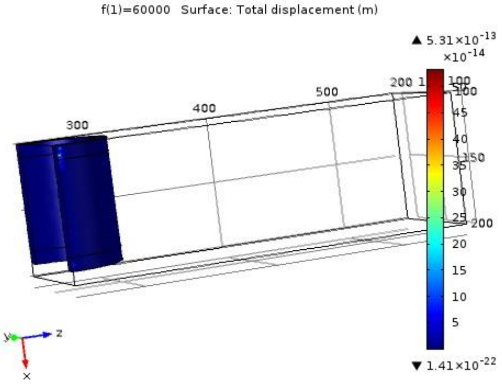
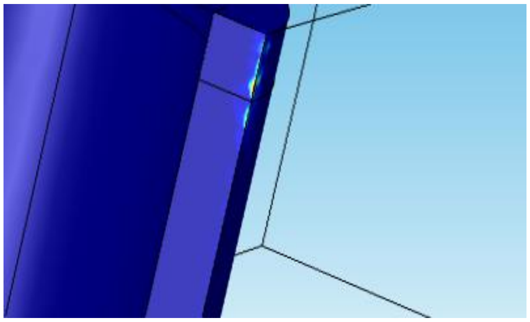


**Figure 4 &5**.Total Displacement on the Dam body.



The default plot displays the von Misses stress distribution together with an exaggerated (automatically scaled) picture of the deformation. As expected, the high stress values are located around the edges. The maximum von Misses stress remains below the yield stress value , which validates the choice of a linear elastic material to analyze this structure.

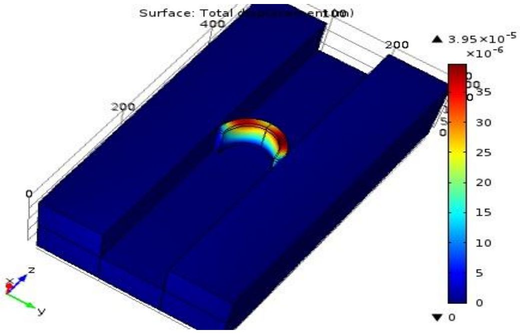


**Figure 6**. Surface total Displacement of the Dam body.

The Von Misses stress distribution obtained by FEA analysis of the Dam body in that that Von Misses stress is at maximum towards the upstream bottom side of Dam body .Sometimes this yield will cause deformation or cracks on the structure for that the Von Misses stress yield point value is less than the actual value then only the design is safe. In short our duty is to keep the maximum value of Von Misses stress induced in the material less than its strength by the use of different techniques which are going to do research as a continuation of this work. In the figure below you can see that the Dam body base remains fixed while only the edges are deformed.

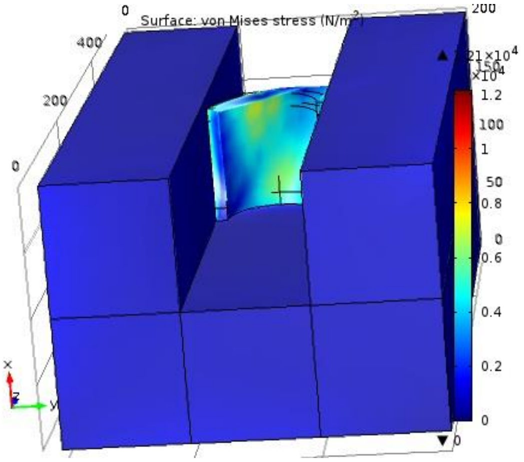


**Figure 7**. Surface von misses stress

The 2D model geometry consists of a horizontal flow channel in the middle of which is an obstacle, a Dam body structure (Figure 1). The fluid flows from Right to Left on the U/S side, and it imposes a force on the structure’s walls resulting from the viscous drag and fluid pressure. The structure, being made of an undeformable material, under the applied load. Consequently.

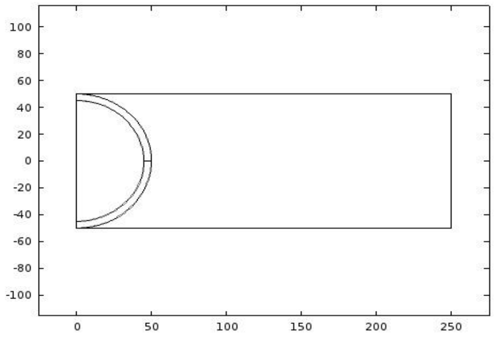


**Figure 8**. 2D dam body in U/S model

The Navier-Stokes equations that solve the flow are formulated for this moving coordinates.The structural mechanics portion of the model is solved by COMSOL Multiphysics with its fixed coordinate system as usual.

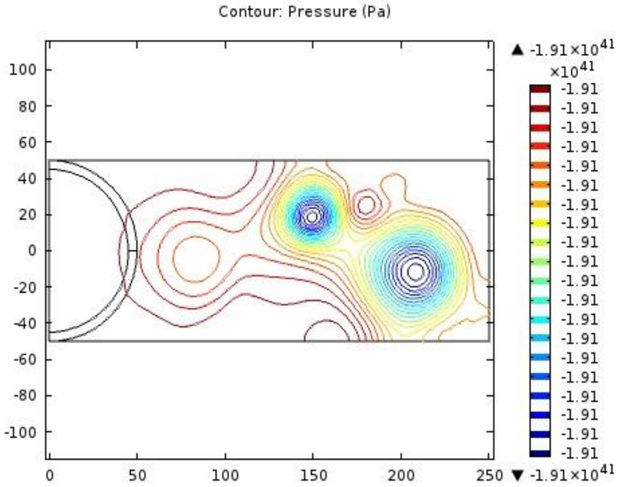


**Figure 9**. Contour pressure on the U/S of the Dam.

The boundaries of the narrow structure are the only moving boundaries of the flow channel. Therefore the contour pressure also Solved with COMSOL Multiphysics 4.4 has its largest values near the structure. It further illustrates this point; it compares the average inflow velocity to the horizontal mesh velocity and the horizontal mesh displacement just beside the top of the structure.

Most of the time the deformation follows the inflow velocity quite closely. Whenever the inflow velocity starts to decrease, the deformation also decreases, which you can observe as the negative values on the horizontal mesh velocity. Toward the end of the simulation, when inflow and structure deformation approach their steady-state values, the mesh velocity also decreases to zero.

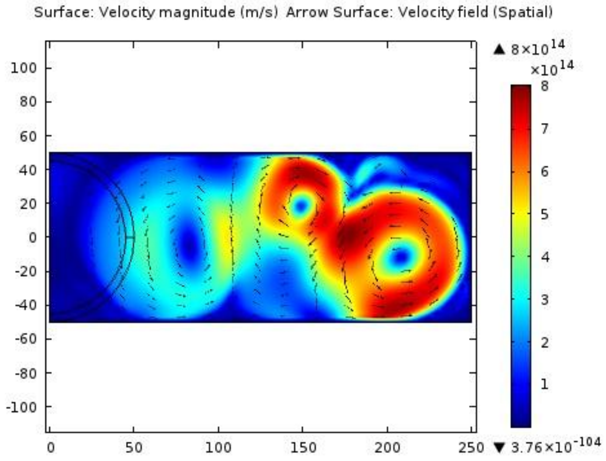


**Figure 10.**Velocity magnitude on the U/S of the dam.

## 6. Conclusions

The parametric computational model of double curvature arch dam was developed using the COMSOL multi physics .The model captures the Pressure Acoustics and Acoustic-Solid Interaction for the Frequency Domain interface between the concrete arch body and the fluid .It was used to Predict the stress strain and also the deformation & displacement for the corresponding follower loads including the impounded water on the upstream face of the dam.

## 7. References

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