PHOENICS Case Study: Environmental
Hydro Dam Water Intake

Introduction

A PHOENICS study was requested, via CHAM agents INORES Inovatif Teknoloji, on behalf of Turkey's General Directorate of Electrical Power Resources Survey and Development Administration (EIE AS), concerning the water intake system for the "Cetin Baraji" Hydro Dam located in Siirt, Turkey. EIE AS approves all electricity generation projects in Turkey. PHOENICS successfully predicted flow behaviour in the hydro-power intake structure. The software can also be used to assist hydraulic design of stilling basins, spillway structures and other regulatory structures.

A hydro-power plant uses the potential or/and kinetic energy of water to produce electricity. A typical hydro-power plant is shown in Fig1. The engineering design and assessment of a hydropower facility necessitates understanding complex water motion. The flow phenomena occurring in such problems are highly three dimensional, turbulent and unsteady in nature. For many years, physical-model testing served as the only medium to attain some insight into the unsteady, three-dimensional flow behaviors of such problems. As physical testing is time consuming and expensive, it cannot be employed for optimization of the hydraulic design. Further, the high hydrostatic pressure prevailing in real life cannot be replicated in a scaled down experiment. CFD offers a cost-effective alternative. CFD solutions have proved to be quick and accurate and hence they can be very useful for design evaluation and optimization.

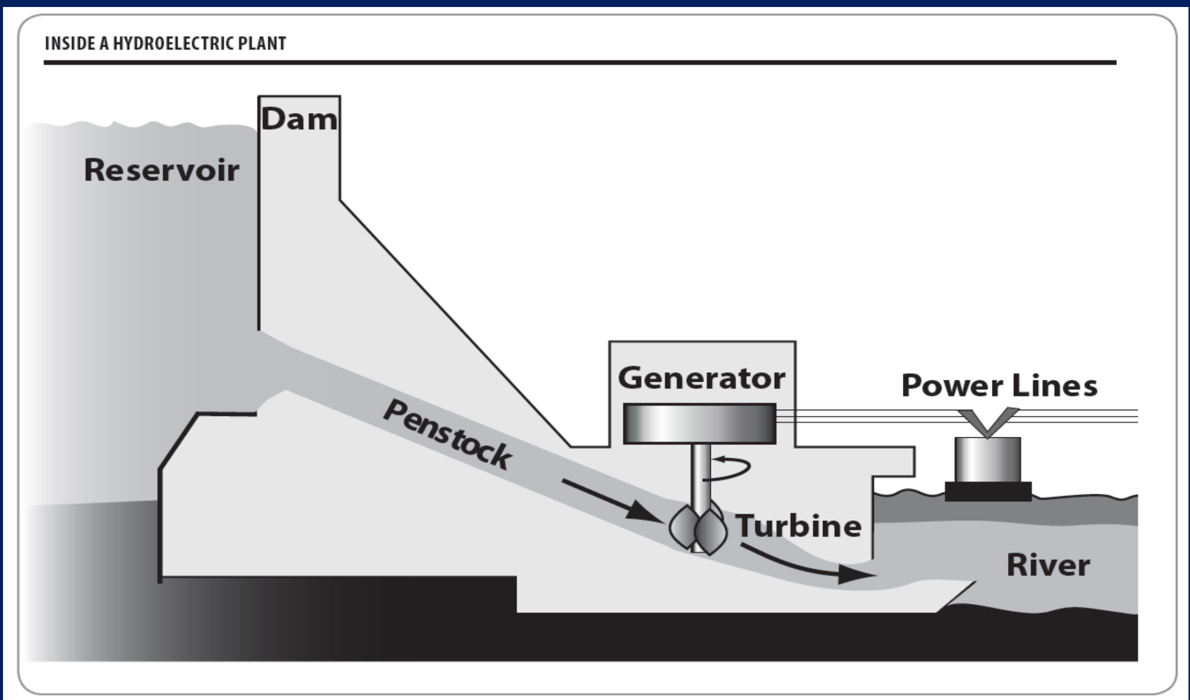

Figure 1: Cross section of a conventional Hydro electric dam

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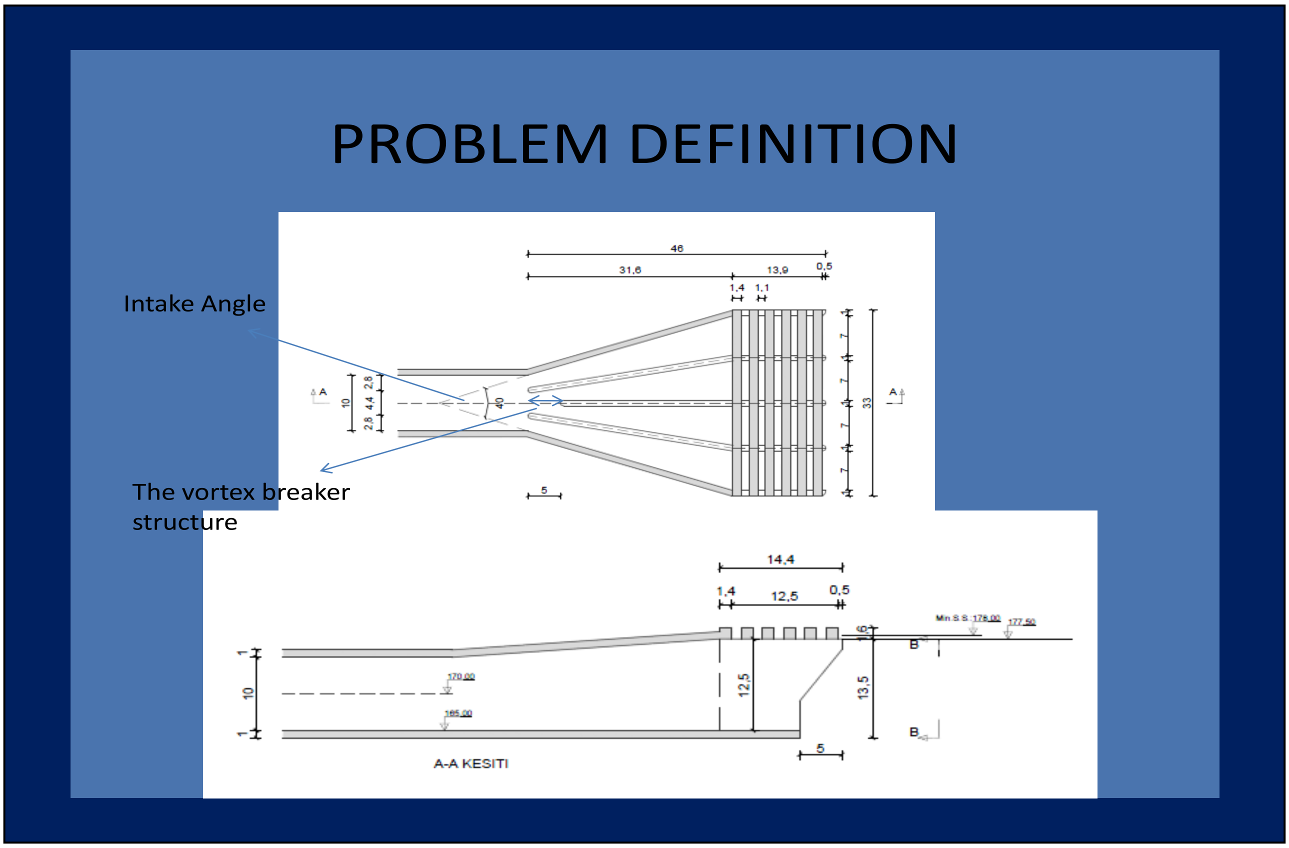
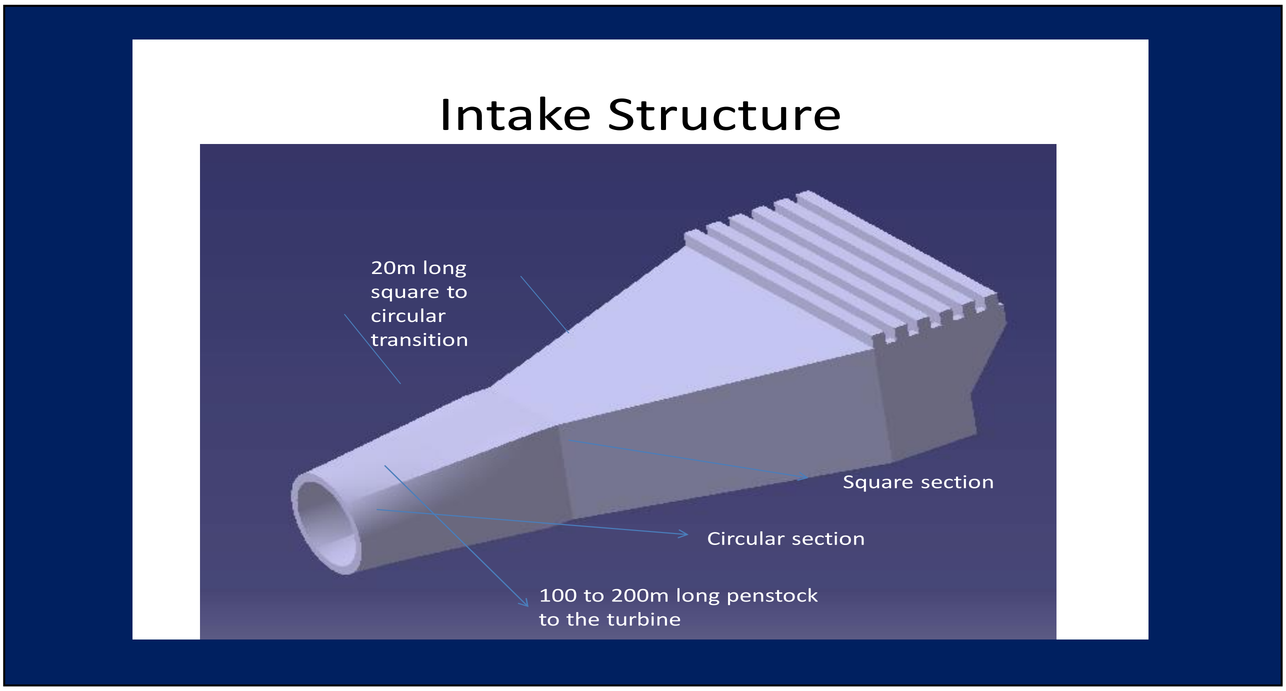


Problem Definition

The structure is a water intake in a dam which carries water to the turbines. The intake is submerged at all times. The “grilled” section is 14.4m long and submerged in the reservoir’s water. The remainder of the structure is enclosed within the dam wall. The structure has four intake channels which narrow towards the outlet. The purpose of the CFD study is to model:

- how the water behaves when entering the structure, and
- the flow of turbulent water flow through the structure, at different water levels.

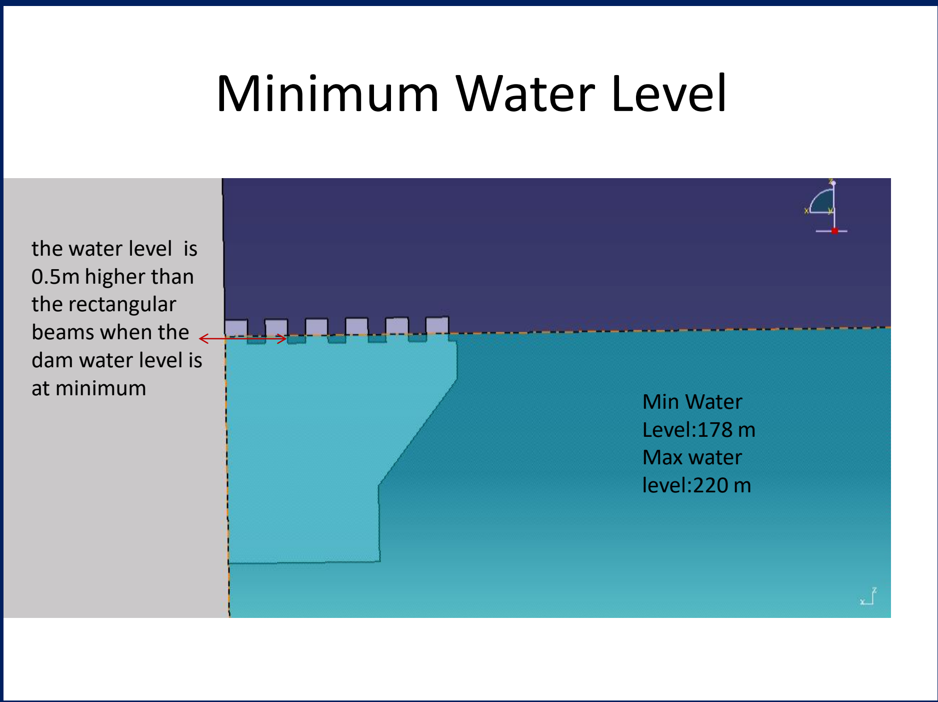


Physical model parameters

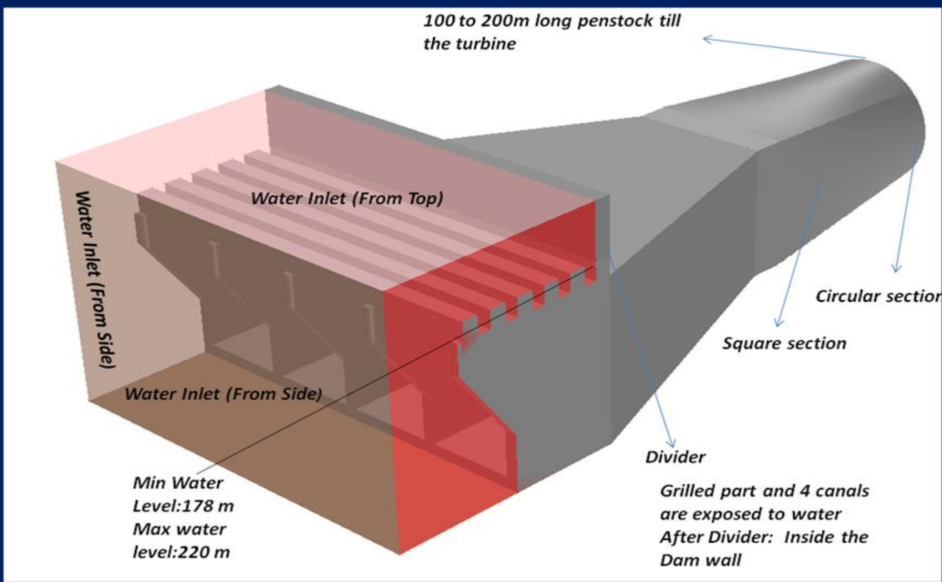
Model Properties:

- Dam Maximum water level is 220m
- Minimum water level is 178m
- Length of the penstock between intake and the turbine is 100-200m
- Turbine type is FRANCIS
- Maximum flow rate of turbine is 350m^3/sec
- Turbine gross power is 400MW

The material structure is concrete. Inlet pressure can vary because of the varying water level in the reservoir.



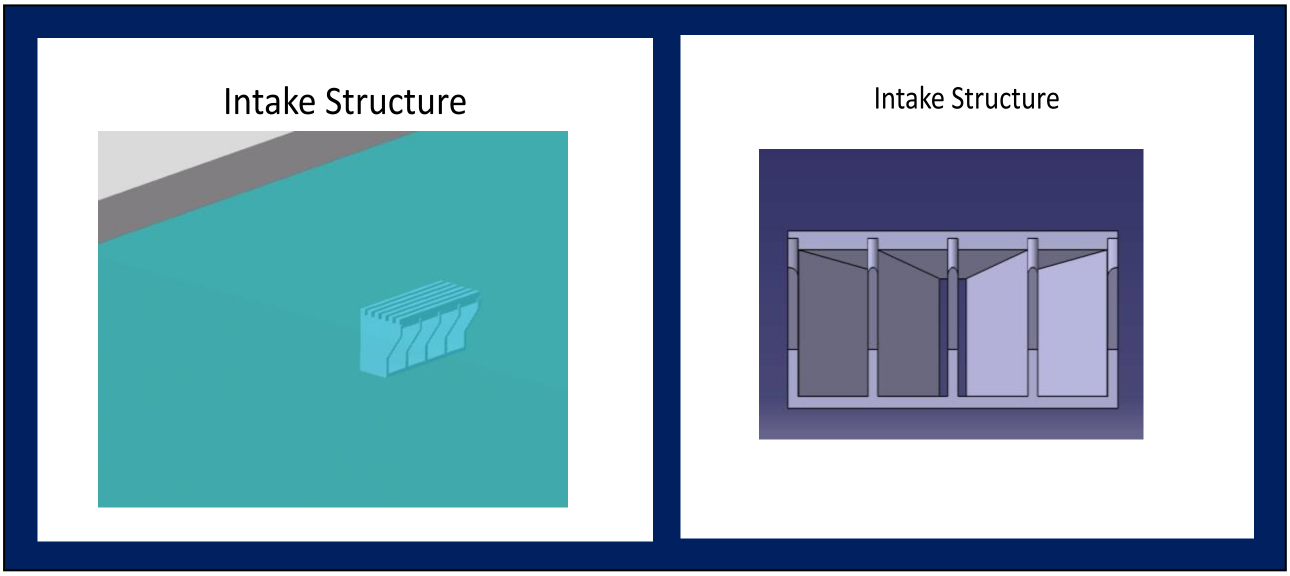
The geometry of the Dam Intake structure was imported as a 3D solid model in STL format.



Imported from CAD

CFD modelling considerations

The water flow through the water intake was modelled both without, and then with, the presence of the water turbine. In the latter case, the effect of the turbine downstream was represented as a resistance through the addition of a "porous" plate. It is Interesting to note that without introducing the effect of turbine as an obstacle, the velocity at the exit is 30m/s, yet after introducing the effect of turbine (via the porous plate) the rate is reduced. Without needing further information about the turbine itself, the resistance coefficient can be adjusted to bring the velocity down to the stated 4m/s observed by the client.



Design Questions

How can one optimise the structure of the intake whilst reducing turbulent effects?
Possible design parameters for possible modification are:

- Intake angle
- Intake structure – vortex breaker position, dimension and angle
- Rectangular beams – height, distance between, and width.

CFD Model Description

Boundary conditions:

Hydrostatic pressure on the top was set based on the maximum head of water. Water inlet from the sides of the dam is set as varying pressure with height using the "INFORM" feature available in PHOENICS.

Outlet pressure is set to atmospheric pressure with varying height using the INFORM command.

Conservation Equations: Continuity, three momentum equations, turbulent kinetic energy and its rate of dissipation. *Fluid properties:* Working fluid is water. Density: 998kg/m3. Viscosity: 1.006E-6

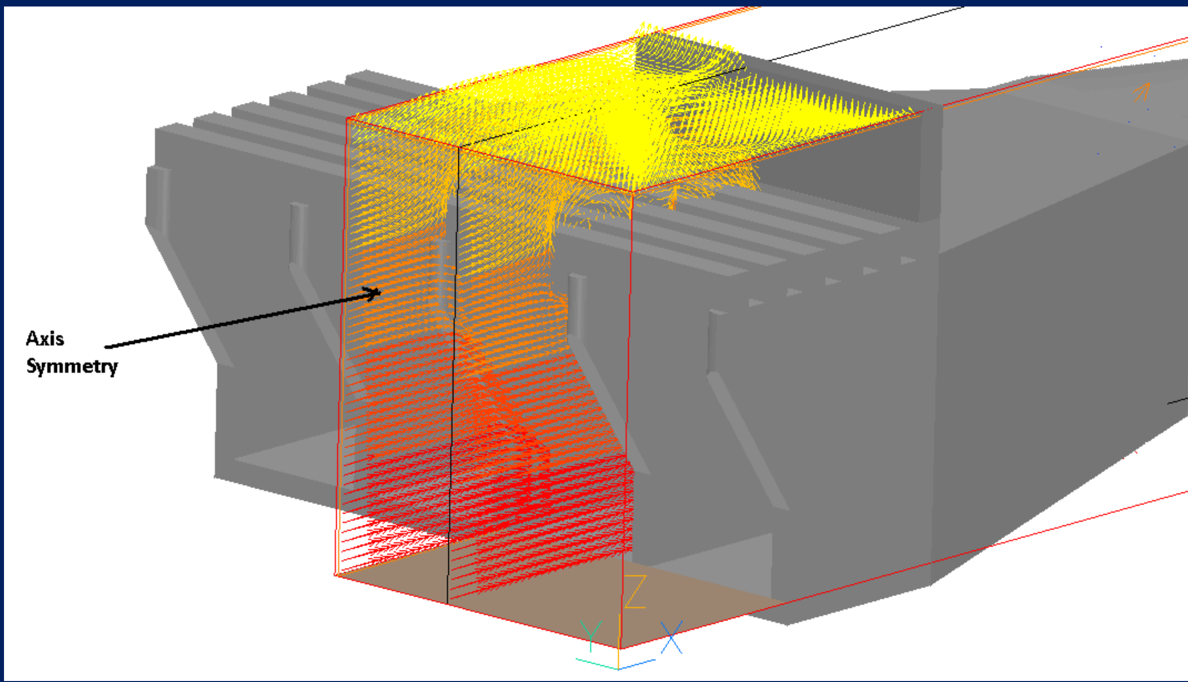
Computational Domain: Taking advantage of the symmetry of the structure about the XZ plane, only half of the structure was modelled and symmetry boundary condition was employed on the south face.

Numerical Parameters: PARSOL Cartesian cut-cell solver with residual cut-cell volumes of 5%. Mesh: 149 * 61* 55 = 0.5 million cells

Sweeps & Run time: Total number of sweeps: 6000. Elapsed run time: 11hrs.

[Note: This was a demonstration case so no optimisation was made in respect of mesh, relaxation practices, and iteration numbers.]

Result Images

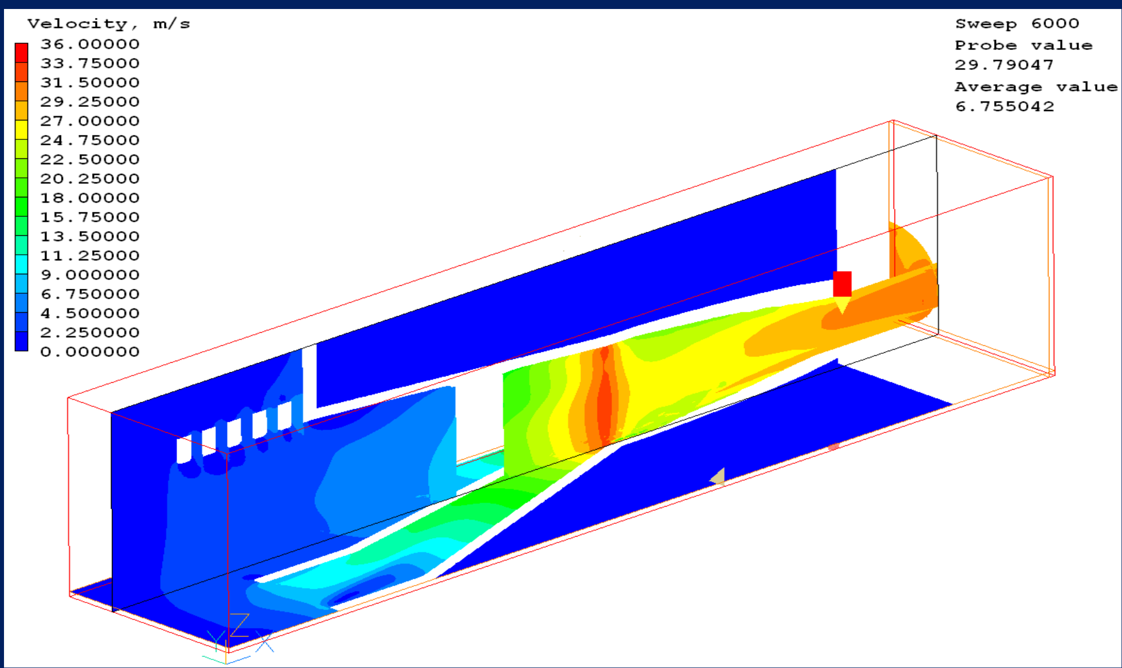


Two Different Approaches were modelled:

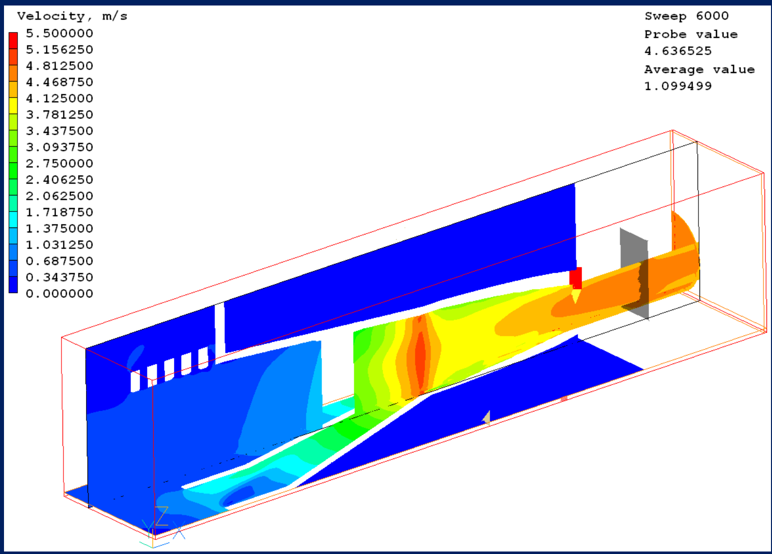
Case1: Modelling the dam without introducing the effect of Turbine resistance.
Case2: Modelling the dam introducing the effect of Turbine resistance.

Results

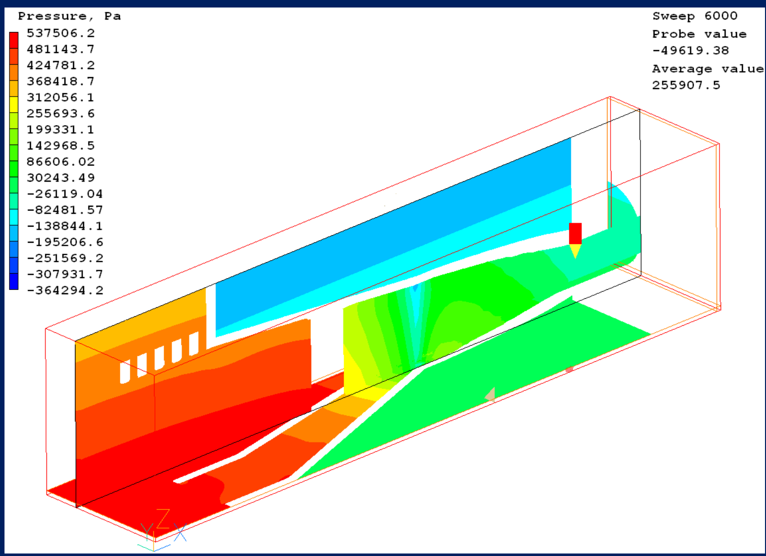
The flow fields of the dam 'with' and 'without' considering the effect of turbine resistance are presented below.



(a) At Y = 12m, Z = 0.5m _ Without the turbine effect



(b) At Y = 12m, Z = 0.5m _ With turbine effect



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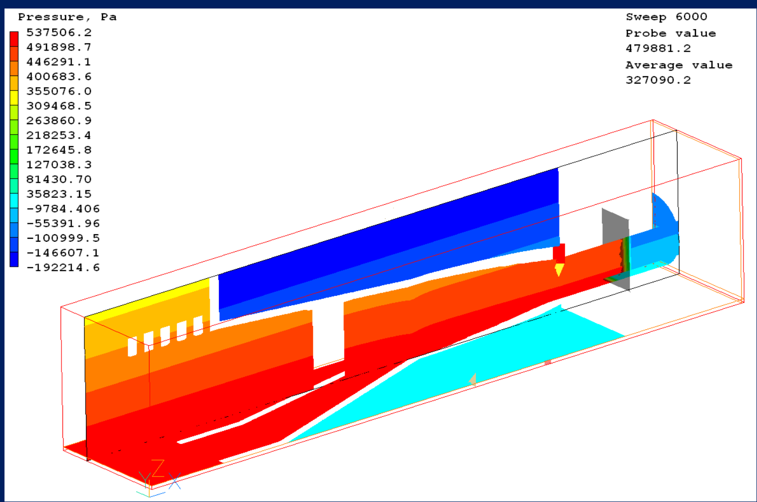

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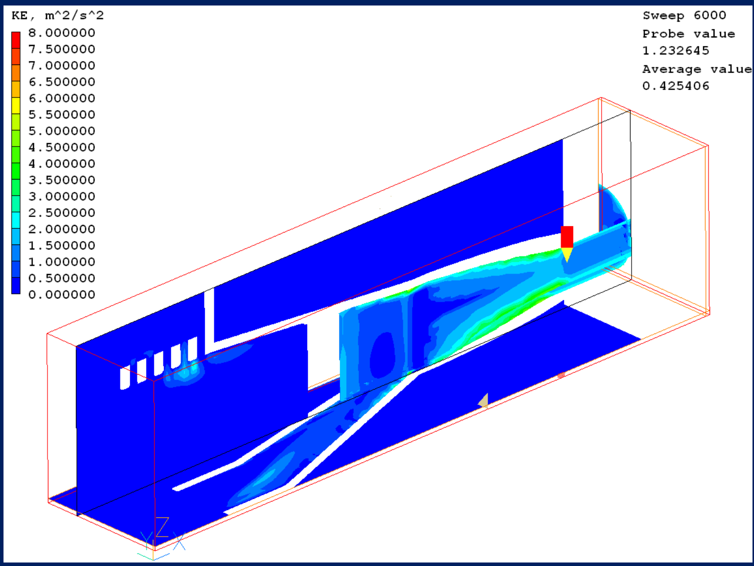

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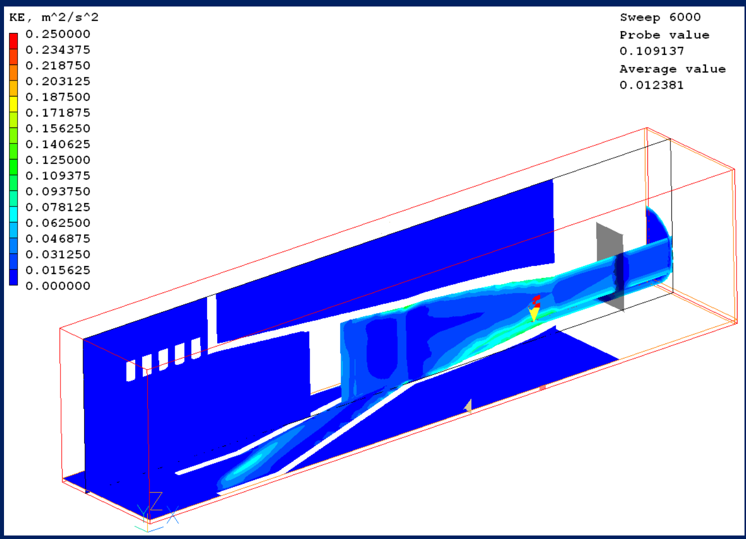

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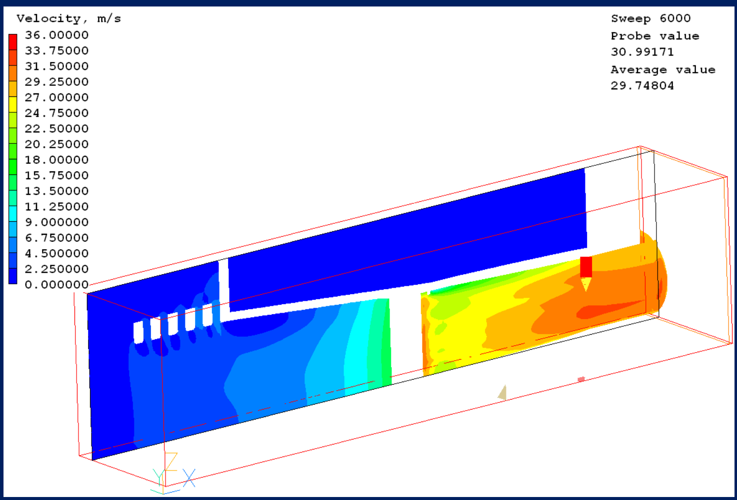
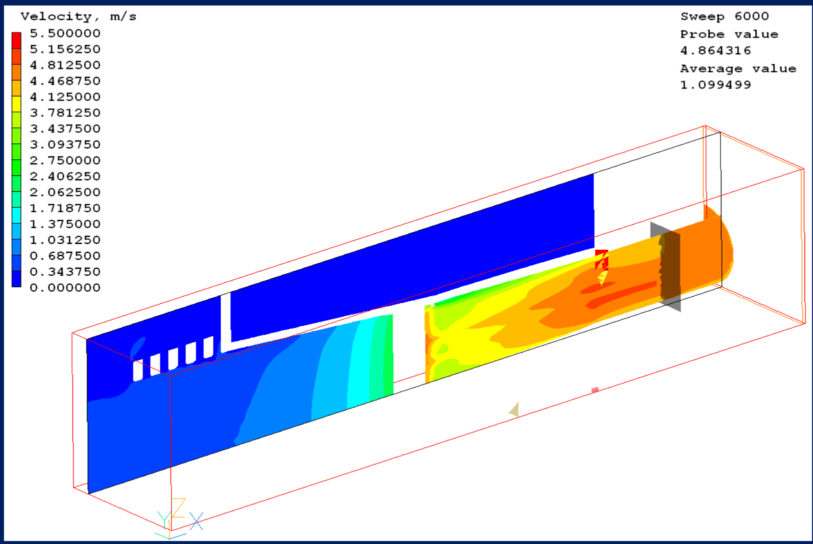
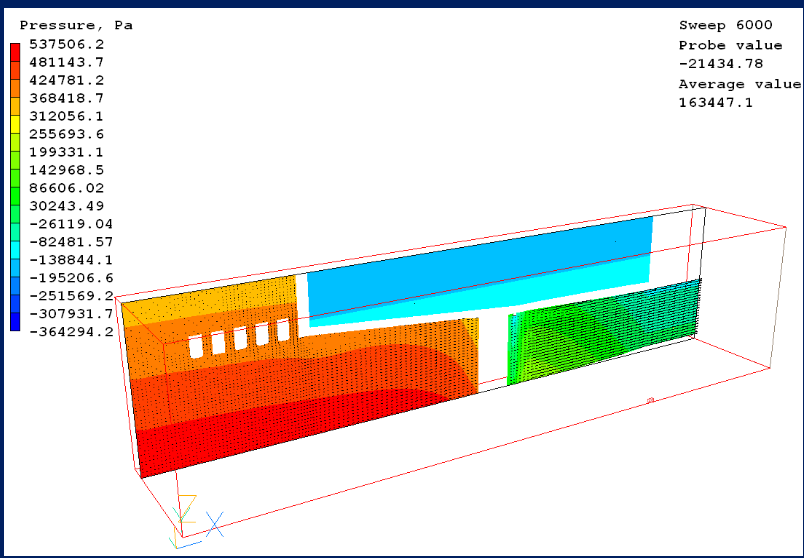


(a) At Y = 14m _ Without the turbine effect



(b) At Y = 14m _ With turbine effect



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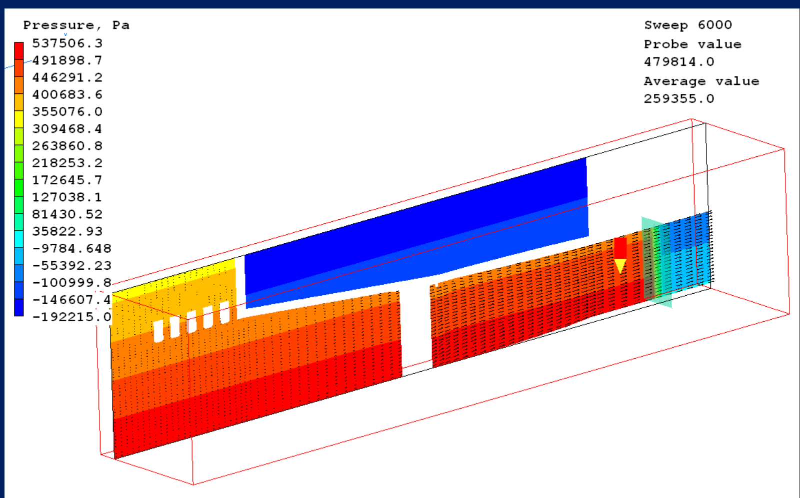
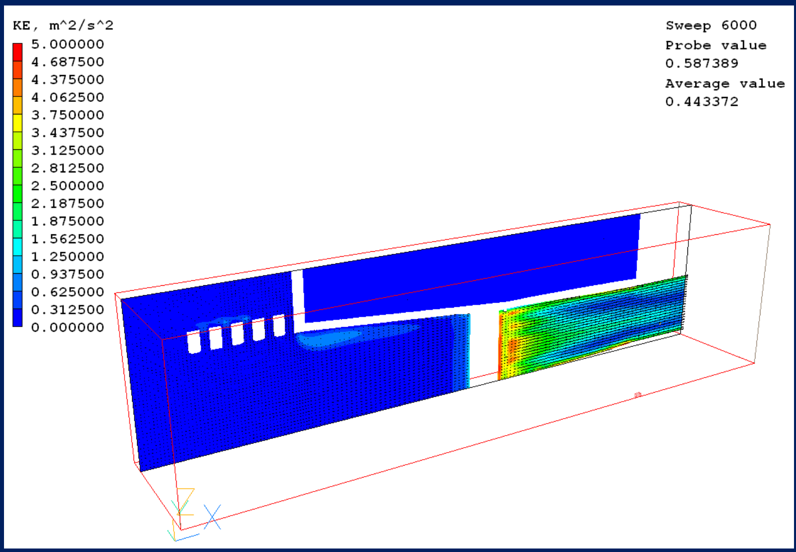


(b) At Y = 14m _ With turbine effect



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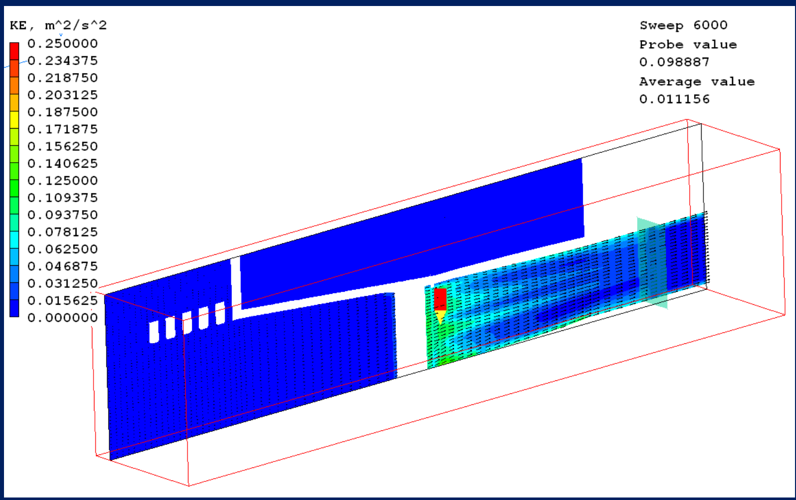

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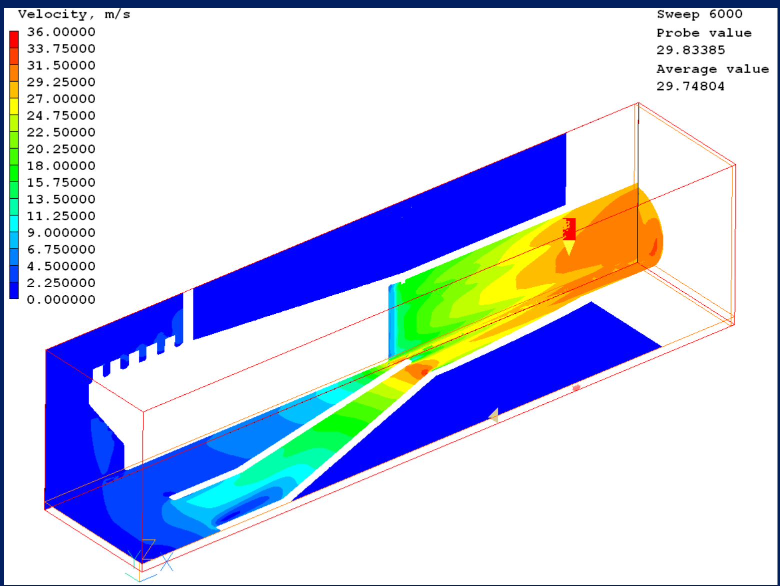
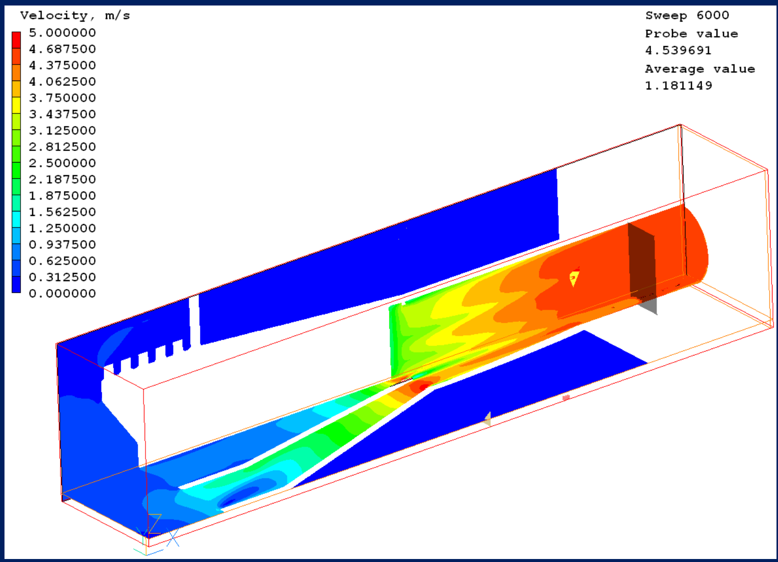
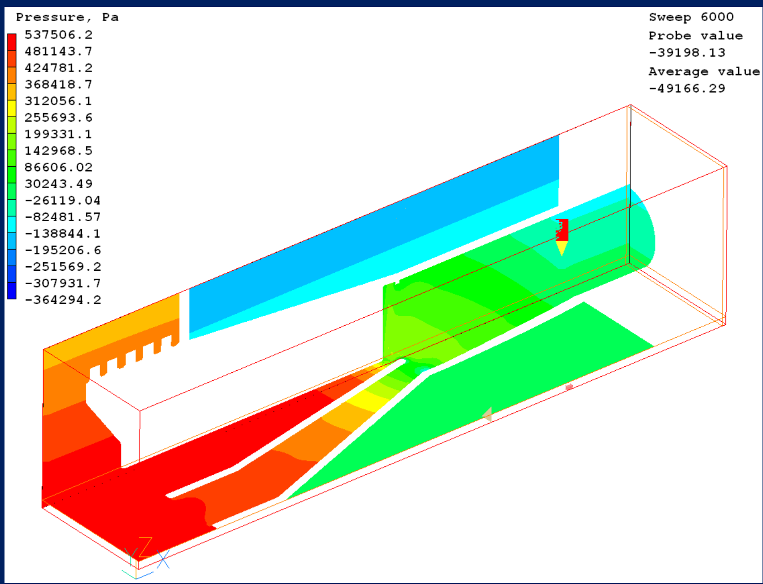


(a) At Y = 16.5m, Z = 1m _ Without the turbine effect



(b) At Y = 16.5m, Z = 1m _ With turbine effect



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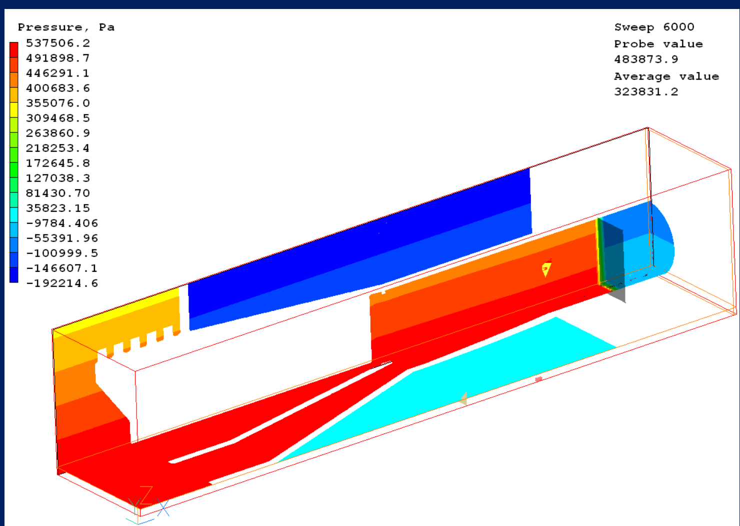
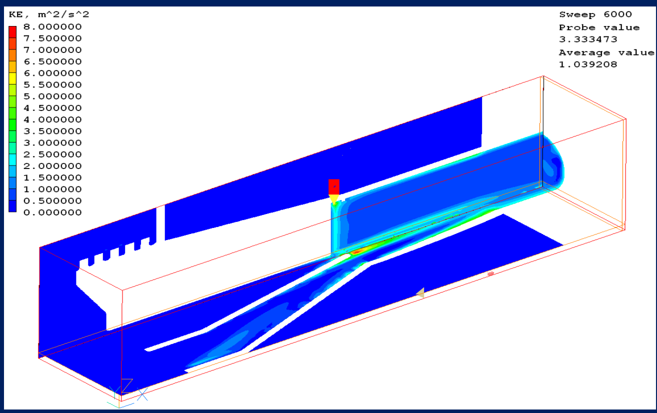


(b) At Y = 16.5m, Z = 1m _ With turbine effec



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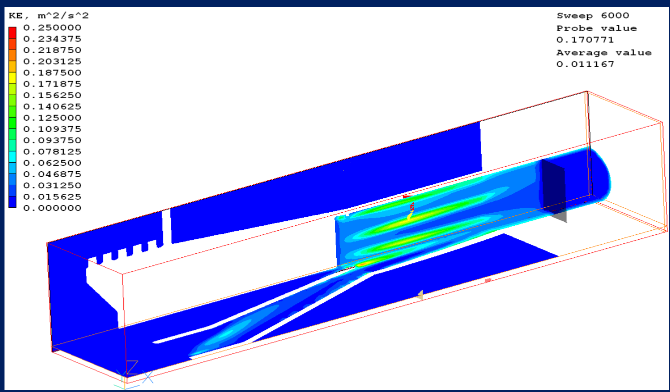

(b) At Y = 16.5m, Z = 1m _ With turbine effect

Summary

As said earlier, PHOENICS proved able to predict flow behavior occurring in the hydro-power intake structure. The software can be used to assist hydraulic design of stilling basins, spillway structures and other regulatory structures

The water flow in a hydro-power intake and spillway structures showcases some of the complex problems in fluid mechanics. The numerical strategy of modeling the hydro-power intake structure of “Cetin Baraji” using the PHOENICS CFD Solver was presented. The preliminary results presented include the velocity, pressure field and turbulent characteristics occurring in the flow. In the numerical simulation, the effect of the turbine resistance was modeled using a porous plate analogy. The net bulk velocity at the exit considering the turbine resistance and at maximum water head was about 4.54 m/s resulting in a maximum fluid flow 356 m^3/s, while the actual fluid flow was 350 m^3/s; that supports the plausibility of the CFD results.

The CFD model can be used to optimize the design of the intake structure. The design parameters for optimization include the inlet angle, size and position of the vortex breaker and size and position of the beams in the inlet grill. Once optimized, the intake structure should generate less turbulence and hence become more efficient.

As a result of this study, it is anticipated that all project applicant firms will be encouraged to employ CFD techniques for testing new intake designs. Considering the hundreds of applications in Turkey for hydro projects, this means a large market for CFD projects and associated software sales.

Note: Results presented herein are qualitative and generated using a base line grid that has not been subjected to grid independency check. Grid adaption and carefully defined under-relaxation factors are likely to result in greater accuracy, quicker convergence and lesser computational effort.