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**Technical Paper**

# *CFD Application in 3D flow filed modeling of a large dam reservoir*

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***ABSTRACT***

In the present paper, a 3D numerical model has been applied to predict the flow hydrodynamics around power intakes within the Dez dam reservoir. The Dez dam is a 203 m high, double arch concrete dam which is constructed by Italians in 1962. Since then, sedimentation in reservoir has continued and since the dam does not have bottom outlet, the reservoir bed level is raising by a rate of about 2.5 meter per year. The power intake invert level is in 270 m asl and on the basis of 2007 hydrography results, the reservoir bed level has reached the level of 260 m asl that means the sediment level is just 10 meters below the power tunnel intakes. The applied three-dimensional model is a finite volume model, which can model curvilinear and non-orthogonal domains and uses the fully 3D time averaged Navier Stocks equations. For incorporating the effects of turbulent flow in computations, an advanced turbulent model, named $k-\omega$ model has been applied. The present model results for flow field around power intakes show that for the present conditions (sediment level of 260 m and intakes level of 270 m ) some limited amount of sediments is entering power tunnels and if no rehabilitation measures is considered, more sediment will enter the power tunnels in the coming years.

***Keywords***

3D numerical model, dam reservoir, sedimentation, k-w turbulence model

## 1. Introduction

Double arch Dez dam has been constructed in a narrow gorge in 1962 southern Iran. It has three irrigation outlets at level of 222.7 m asl, two power intakes at elevation of 270 m asl. No bottom outlets have been designed and installed for Dez dam and consequently the sediment-entering reservoir cannot be evacuated easily.At the design stage, it was supposed that the sediment accumulation in the Dez reservoir (see Fig. 1) 840 million m3 for 50 year, i.e. equivalent to dead storage volume of reser voir to the elevation of 290 m. This estimate was made based on soil and water conservation activities at the upstream of reservoir including reforestation program. However, none of these programs were done. Nevertheless, out of an initial reservoir volume of around 3.3 billion cubic meters at the elevation of 350 m, the available storage in 2002-2003 was found to be 2.7 billion $m^3$ which corresponds to a volume loss of about 19 percent. A large part of the accumulated sediments deposited in a way to form a delta

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which is slowly progressing to the dam body.

On the basis of latest hydrography data of reservoir, done in 2007, the reservoir bed level is at 260 m asl i.e. just 10 m below power intakes. The high level of reservoir bed caused floods and density currents to enter significant amount of suspended sediment into power intakes and turbine annually in flood seasons. This dam is the most important dam in Iran, adjusting and controlling the country's electricity network frequency. There is the fear that turbines are damaged seriously loose power productivity in the coming days, if no action is taken.

By considering the importance of Dez dam power generation, the present study is devoted to the 3D numerical simulation of flow field in the reservoir at the area close to power intakes and accordingly qualitative analysis of sediment transport at the area around intakes.

A fully 3D numerical model with $k-\omega$ turbulence model working in non-orthogonal curvilinear coordinate system has been implemented. The finite volume method is collaborated to discrete the governing equations.

## 2. Flow field simulation and sediment transport qualitative prediction

In order to simulate the flow hydrodynamics and sediment transport at the area close to power intakes, three-dimensionally, a region within the reservoir where is limited to downstream, upstream, left and right to dam body, a distance of 320 meter into reservoir, left bed rock and right bed rock has been considered (see Fig. 2 and 3). The flow field domain is from elevation of 260 m asl (bed level) to the level of 334 m asl (the maximum water level is 354 m asl).

The 3D computational mesh of this domain has been made. Using clustering method, the mesh dimensions are chosen to be finer at the areas with higher gradient, like intakes entrances. Fig. 4 shows the applied computational grids of Dez dam reservoir in

Fig.1: General view of double curvature arch of dez dam of Dez

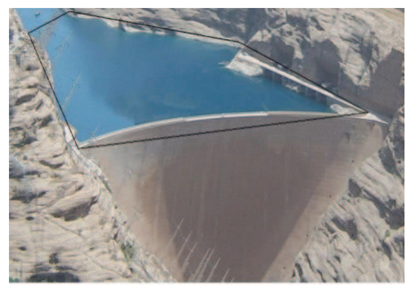

Fig.2: Perspective view of simulated area of Dez dam reservoir (inside the restricted area by black line)

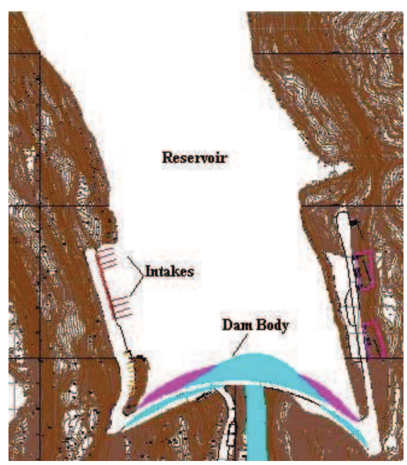


Fig.3: Plan view of simulated area of Dez dam reservoir

the considered domain. The total node number of this 2932739 cubic meter simulated volume is 7357.

### 2.1. Governing Equations

The numerical model simulates the flow field by applying the Reynolds-averaged Navier-Stokes (RANS) equations as (Rodi 1993):

$$U_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial}{\partial x_j}(P\delta_{ij} + \rho\overline{u_i u_j}) \qquad (1)$$

and the continuity equation:

$$\frac{\partial U_i}{\partial x_i} = 0 \qquad (2)$$

where $\rho$ is the fluid density, $\delta_{ij}$ is the Kroneker delta, $U_j$ are the components of local time averaged flow velocities, $P$ is dynamic pressure, and $-\rho\overline{u_i u_j}$ are the turbulence Reynolds stresses.

As the turbulence in the flow affects velocity, it is necessary to use an advanced turbulence model to handle a 3D flow problem. In this study, the turbulence stresses are modeled with the aid of the Boussinesq relations (Rodi 1993):

$$-\rho\overline{u_i u_j} = \rho \upsilon_t (\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}) - \frac{2}{3}k\delta_{ij} \qquad (3)$$

The $k-\omega$ model of Wilcox (Wilcox 1994, 1998) is used. The eddy viscosity $\upsilon_t$ in the $k-\omega$ model is given by:

$$\upsilon_t = \alpha^* \frac{k}{\omega} \qquad (4)$$

where $\omega$ is the specific dissipation rate and $\alpha^*$ is a low-turbulence Reynolds number damping function for a low $\mathrm{Re}_T$ flow near walls (Wilcox 1994, 1998). The governing equations for $k$ and $\omega$ are given as follows:

$$U_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[(\upsilon + \frac{\upsilon_t}{\sigma_k})\frac{\partial k}{\partial x_j}\right] - \beta^* \omega k + G \qquad (5)$$

And

$$U_j \frac{\partial \omega}{\partial x_j} = \frac{\partial}{\partial x_j}\left[(\upsilon + \frac{\upsilon_t}{\sigma_\omega})\frac{\partial \omega}{\partial x_j}\right] - \beta\omega^2 + \alpha\frac{\omega}{k}G \qquad (6)$$

Where $G$ denotes the turbulence production term, defined as:

$$G = \upsilon_t \frac{\partial U_i}{\partial x_j}(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}) \qquad (7)$$

Other parameters for the used version of $k-\omega$ model (low Reynolds number) are (Wilcox 1994):

$$\alpha^* = \frac{\alpha_0^* + \mathrm{Re}_T/R_k}{1 + \mathrm{Re}_T/R_k},$$
$$\alpha = \frac{5}{9}\frac{\alpha_0 + \mathrm{Re}_T/R_\omega}{1 + \mathrm{Re}_T/R_\omega}(\alpha^*)^{-1},$$
$$\beta^* = \beta_0^* \frac{5/18 + (\mathrm{Re}_T/R_\beta)^4}{1 + (\mathrm{Re}_T/R_\beta)^4}, \qquad (8)$$

Where:

$$\alpha_0^* = 1/40, \alpha_0 = 1/10, R_\beta = 8, R_k = 6, R_\omega = 27/10$$
$$\sigma_w = \sigma_k = 2, \beta = 3/40, \beta_0^* = 9/100 \qquad (9)$$

### 2.2. Boundary Conditions

At the inlet, with assuming the normal working condition for power plant, an inflow discharge of 260 cubic meters per second and consequently an appropriate inflow velocity is considered.

At the outlet, intake faces, pressure is specified at the cell face center, while Cartesian-velocity components and turbulence quantitiesare extrapolated from the interior using a second-order extrapolation.

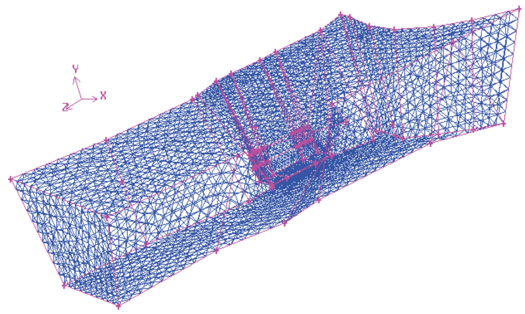


Fig.4: The computational mesh used for flow filed modeling of Dez dam reservoir

For the solid boundary, it is assumed that the center of the element close to a solid boundary is within the log-layer of the wall; hence, the logarithmic velocity distribution is adopted:

$$\frac{U}{u_*} = \frac{1}{\kappa}\ln(E\frac{yu_*}{\upsilon}) \tag{10}$$

where $u_*$ and $\kappa$ are shear velocity and von Karman constant, respectively; and $E$ is a roughness parameter.

At the free surface, a zero-gradient condition is used for the velocity components parallel to the free surface, while $\omega, k,$ and velocity components perpendicular to the free surface are set to zero. In other word, at free surface a rigid lid boundary condition has been applied. This type of boundary condition is only applicable in the flows with level free surface or with low water surface variations (Khosronejad et al. 2008).

## 3. Flow Hydrodynamic Simulation Results

3D Model has been run for a limited 320 meter long reservoir section, between elevations of 260 and 334 m asl, using the above mentioned computational grids. Before that the model was tested against the experimental data to verify its accuracy according of Khosronejad et al. (2008, 2007).

Fig. 5 shows the computed flow filed in the area close to intakes and also fig. 6 shows the variation of velocity with distance from power intakes. As it is shown in this fig. the flow velocity increases rapidly in the area near to the intakes and vice versa. For the present boundary condition (normal operation mode of power plant with a discharge of 260 cubic meters per second), the maximum velocity magnitude around intakes found to be about 1.2 meter per second.

According to velocity increase in the area near intakes, the bed shear stress will increase in that area (see fig. 7 for bed shear stress profile), as well.

The higher shear stress in that area could be related to the high velocity and curving the stream flow, intensively enhancing the turbulence level of flow field and consequently the bed shear stresses. As shown in fig. 7, bed shear stress varies with distance from intake faces. The bed shear stress at the foot of intakes is about 0.005 pa, although it decreases almost rapidly with distance perpendicular to intake faces.

## 4. Qualitative analysis of sediment transport in reservoir by using Flow field results

According to field measurements, the sediment materials deposited in Dez dam reservoir are 2.8 to 9 micro-meter in size (median diameter), density of about 1.5 grams per cubic centimeters, and settling velocity of 20 to 50 micro-meter per second. With regard to these characteristics of sediments material, the critical bed shear stress, using Shields diagram, is 0.00155 pa.

Therefore at the area with a bed shear stress more than this critical value, bed movement will occur. Therefore, the area shown with red line, in fig. 8, is potentially movable and sediment transport will occur at this area.

The flow will transport sediments from this area into power tunnels. A site mission at Dez dam, in late 2007, indicates that there are some sediment accumulated at the penstocks just upstream of turbines and this fact validates the sediment movement into turbine predicted by the 3D model. The area of this potentially movable reservoir bed is about 1480 square meter.

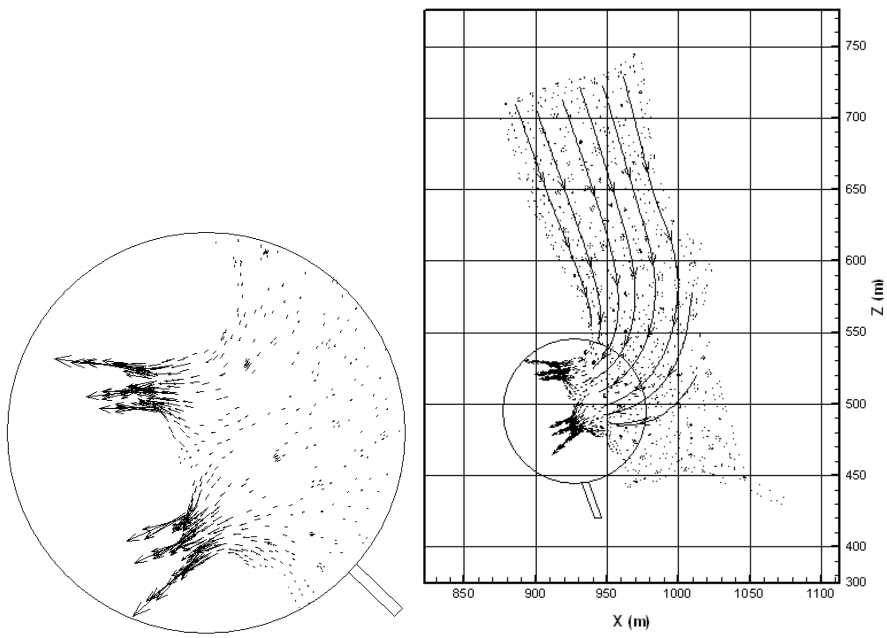


Fig.5: Computed flow field within the reservoir and at the intake faces

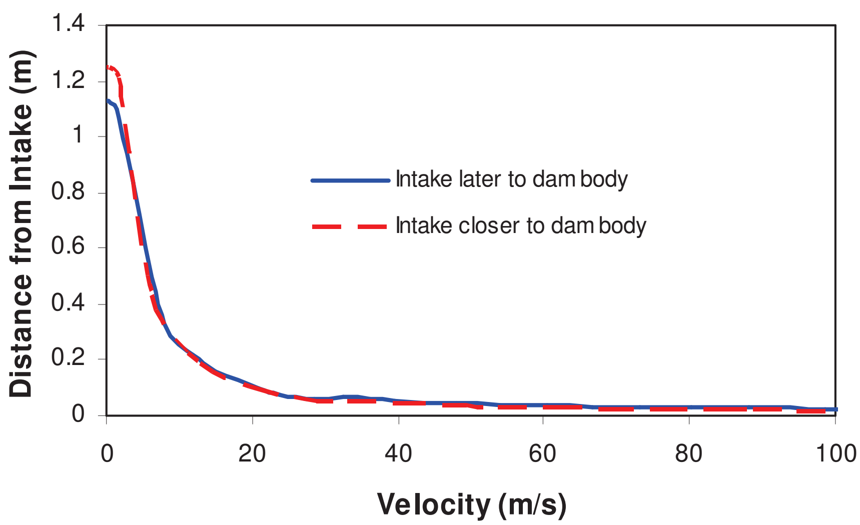


Fig.6: Variation of flow velocity magnitude with distance from intake face

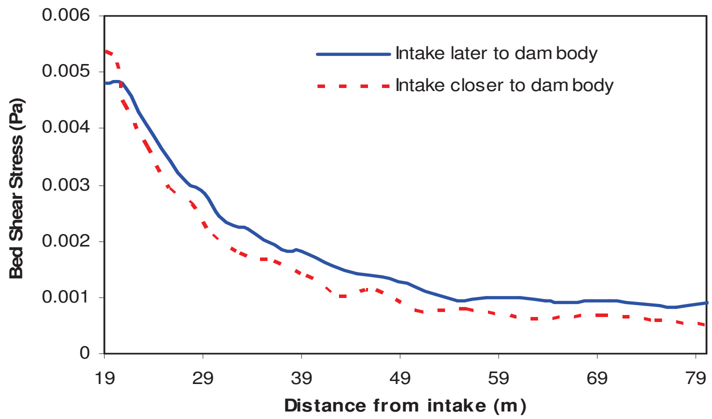


Fig.7: Variation of bed shear stress with distance from intake faces

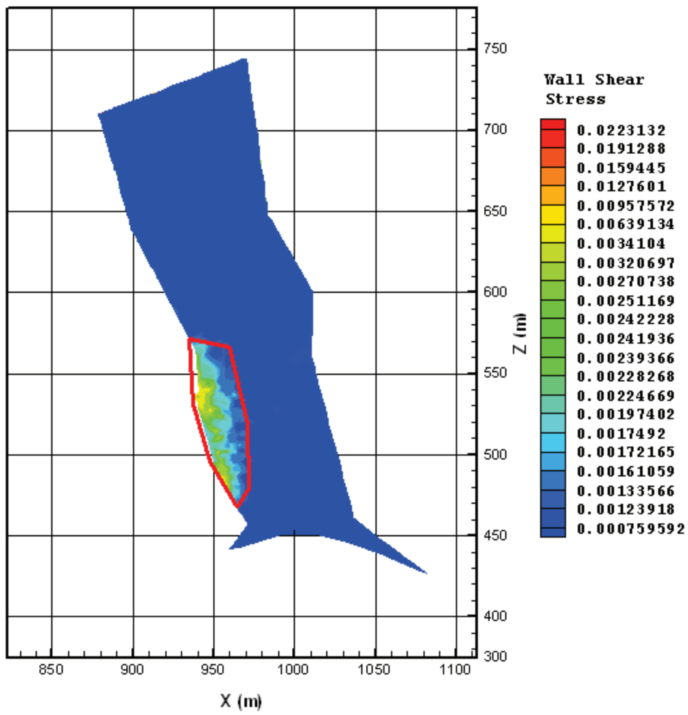


Fig.8: Bed shear stress contours at the area near to intakes; red line shows the area of bed shear stress higher than critical value of 0.00155 pa

## 5. Conclusion

A three-dimensional numerical model has been applied to Dez dam reservoir flow field modeling. To see the turbulence stresses in modeling, an appropriate closure model of $k-\omega$ has been applied. Model results were previously verified. The results, for normal operation conditions, show that the flow velocity has a maximum value of 1.2 m/sec near power intakes decreases with distance. In addition, the turbulent intensity increases in the area near intakes entrance resulting in increasing bed shear stress near intakes. Therefore, the existing bed shear stress (at the area close to intakes) exceeds the critical value (for sediment material condition at Dez dam situation) causing sediments entrain into flow toward intakes and moving into power tunnels, from an area of about 1480 square meters (see fig. 8). Operation team of Dez dam have reported that there are some sediments accumulated in the chambers just upstream of turbines by which the results of this modeling efforts is validated. To preserve this vital dam, some major steps must be taken, releasing accumulated sediments to downstream (Khosronejad, Salehi 2006).

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