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Analysis of the Flow Structure and its Influence on the Operation of a Wastewater Pumping Station*

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Abstract. *The hydraulic phenomena occurring at the entrance of a pumping station are crucial in order to ensure the required operation conditions. Under the circumstances of an undesired flow regime a faulty functioning of the pump units can occur. Such a case was studied by the authors of the present paper. As a consequence of the hydraulic system particularities and due to the local conditions at the inlet of the pumping station, the designed operation parameters were only occasionally achieved. Additionally, shortly after commissioning, the pump rotors were damaged. Starting this point on the Technical University of Civil Engineering Bucharest team studied, based on field measurement and using the expert software Fluent for CFD, the phenomena which caused the aforementioned operation problems. Thus, the streamlines and the velocity field in the given situation were modeled and analyzed. Based on this study several conclusions about the flow characteristics were driven, and a clearly point of view about the causes that are responsible for the poor operation parameter was issued.*

Key words: flow structure, sewerage system, Fluent CFD, pumping station

1. Background and aims

Short after the commissioning for the pumping station serving the first treatment line of a municipal wastewater treatment plant, operation problems were reported. Mainly these are related to the designed pumping capacity (10 m^3/s) that is achieved only for short operation periods.

In their efforts to identify and remediate the problems that could lead to this situation the owner of the pumping station together with the designer and the contractor of the works developed several investigations. The conclusions of these studies revealed rotor damages that could be caused by erosion and/or cavitation. Also the low quality materials used for the pumps (unprotected cast iron) have favored the erosion process.

For identifying the real causes which can be responsible for such phenomenon and to eliminate them, the operator of the sewerage system requested to the Technical University of Civil Engineering of Bucharest (TUCEB) a new expertise on the

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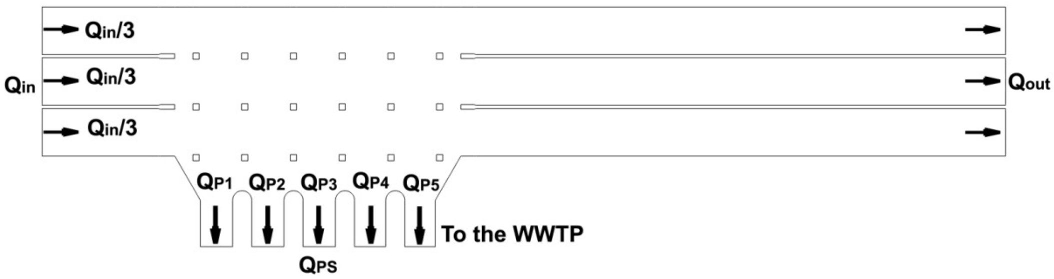
operation of the pumping station which aimed the solutions for solving the reported problems. To achieve these objectives the technical expertise pursuit the development of studies in the hydraulics field focused on all the possible causes leading to the malfunction of the pumping station.

Beside the data and technical documents provided by the operation personnel of the sewage system, a onsite monitoring campaign was carried out by the TUCEB team. The developed technical analyses has revealed a very complex hydraulic system which consists of the main collector, a three way rectangular gallery, a junction were the flow splits, part of the wastewater flows to the pumping station and part downstream to be discharged in the emissary. In the discharge section is a sharp crested weir controlling the water levels upstream.

One of the expertise topics carried out by the TUCEB team is related to the influences of the local conditions and their effects on the flow structure. In order to analyze these problems a numerical model was carried out. The obtained results offered a view of the flow phenomena occurring at the suction chambers inlet. Based on the results of the study several conclusions on the causes leading to the mentioned problems were driven

2. Model description, modeling conditions and obtained results

The domain of interest for the numerical study is the junction between the main collector and the suction chambers inlet (figure 1). In order to analyze the flow conditions and the flow structure, a steady state 2D model using the ANSYS FLUENT code was developed.



Q_{in} – the flow rate upstream junction 1; Q_{out} – the flow rate downstream junction 1; Q_{PS} – the flow rate pumped to the waste water treatment plant (WWTP); Q_{P1}… Q_{P5} – the flow rate pumped by each pump

Fig. 1. The analyzed domain; main collector - pumping station junction.

The fluid used in the modeling process is water, considered to be incompressible for the associated conditions of the study. The pumped flow rate was assumed to be half of the total quantity (10 m^3/s) and equally distributed to the five pumps. The other half leaves the junction and flows downstream.

The Reynolds number value obtained using the characteristic length of the main collector reveals the turbulent character of the motion. Therefore, for the simulations, the Navier-Stokes and the continuity equations in the Reynolds-averaged manner (RANS) were used. For the closure problem the Boussinesq linear approximation was used. Thus, for the turbulent viscosity modeling two additional equations were solved. One for the turbulent kinetic energy transport (k) and the other for its specific dissipation rate (ω) [1].

The adopted turbulence model was the k-ω SST, a hybrid between the k-ε and the k-ω model [1]. The model uses a k-ε formulation for the free flow domain, avoiding thus the disadvantages of the k-ω from the initial conditions point of view and a k-ω for the boundary layer. This is achieved by expressing the k-ε model in a k-ω manner. The gradual transition between the two areas is provided by defining of area depended "mixing" functions which activate the k-ω or k-ε formulation and also by introducing of an diffusive term in the transport relationship of ω [2].

The used software integrates the above mentioned equations using the finite volume method [3]. The chosen solver is a pressure based one. For the momentum, continuity and the specific turbulence model equations discretization a second order scheme was used.

The domain of interest includes the junction, the upstream and three way rectangular galleries and the pumping station inlet. For the numerical study the considered domain dimensions are three specific lengths upstream and fifteen specific lengths downstream the junction.

The incoming flow rate is considered to be equal distributed on the entire upstream boundary of the considered domain. Each pumping unit ensures a 2 m^3/s maximum flow rate. For each of the three flow paths, at the downstream limit, a constant head boundary condition was considered. Figure 2 shows the grid and the considered boundary conditions, used for the modeling of the fluid domain.

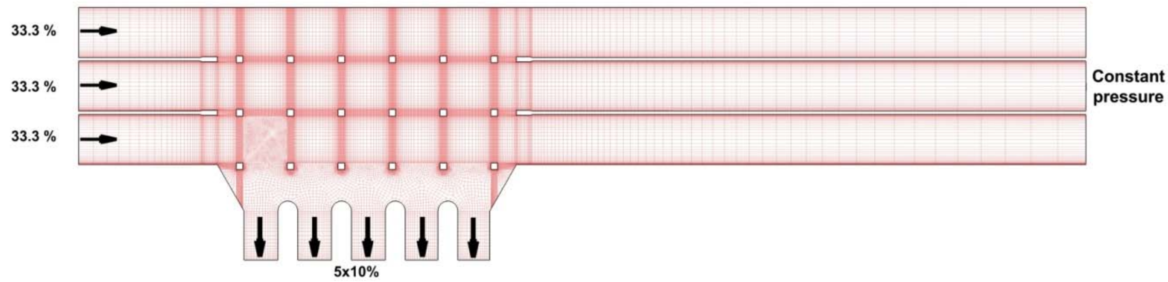


Fig. 2. The grid and the boundary conditions.

The model vas calibrated using the on-site measurements carried out by the TUCEB team and the data delivered by the operator.

The pumped flow rate is uniformly distributed to the five pumps and is half of the incoming to the junction flow rate. The data obtained from the modeling process shows a velocity field similar to figure 3.

Analyzing figure 3, a strongly non-uniform velocity distribution at the pumping station inlet can be observed. For the given flow conditions, the obtained velocity values are covering a quite large interval. Responsible for this are both the junction geometry and the presence of the structural elements (pillars) influencing the flow structure. The presences of sub-domains with low velocities are leading to favorable conditions for the formation of solid material deposits [4]. In the Romanian technical literature the minimum recommended velocity value for avoiding the formation of solid material deposits in sewerage systems is 0.7 m/s [5]. For larger flow rates, especially in the rainy season, the settled solid material will be transported downstream most of it to the suction chambers.

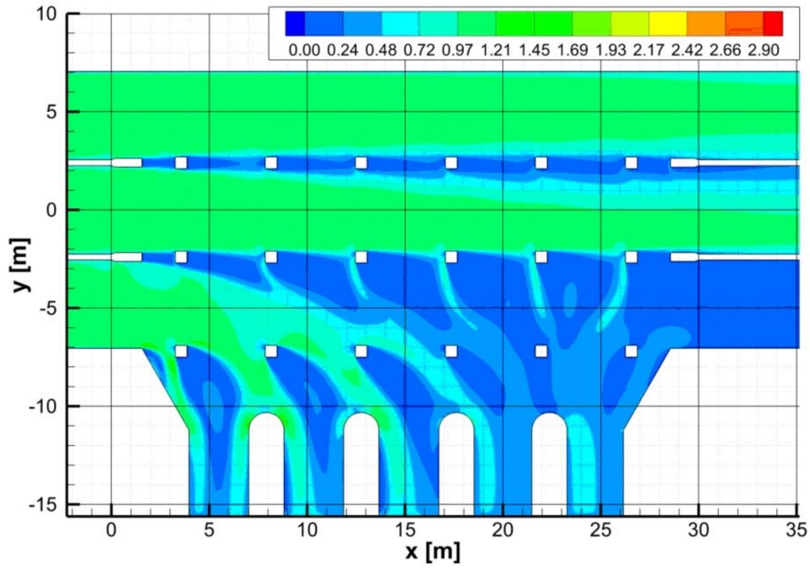


Fig. 3. The velocity field for the main collector - pumping station junction flow domain.

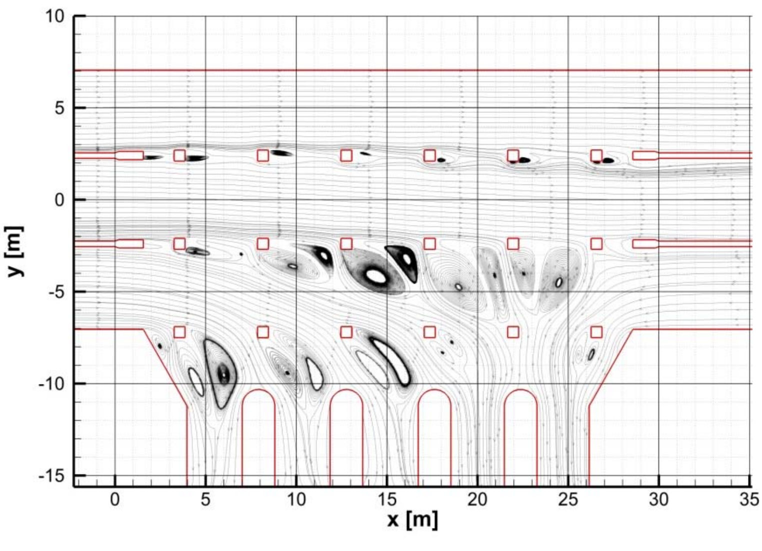


Fig. 4. The streamline structure for the main collector - pumping station junction flow domain.

The streamline representation, plotted in figure 4, show the formation and propagation of von Karman vortices. This is a consequence of the presence of the twelve pillars. After their formation the vortices are spreading downstream, mostly to the coarse screens preceding the suction chambers. The coarse screens are modifying the flow structures formed upstream, and are eliminating also the trapped air in these structures.

3. Conclusions

Based on the modeling of the flow phenomena occurring in the main collector – pumping station junction several conclusions regarding the possible causes leading to the malfunction of the pumping station and the observed rotor damages were driven.

Speaking in terms of hydrodynamics, the entrances in the suction chambers for pumps number four and five (see figure 1) are more “facile”. As shown in figure 4, at the inlet of the last two suction chambers the stream lines are less disturbed and the velocity distribution is more uniform leading to lower velocity values (see figure 3).

At the suction chambers inlet of pumps number 1, 2 and 3 the presence of vortices produces flow irregularities which leads to supplementary head losses to those normally caused by the coarse screens. As a consequence the water level in the aforementioned suction chambers will decrease more. At low wastewater levels in the sewer system, this, together with the designing failures of the suction pipes will lead to the occurrence of air in the pumps, a major cause of damages.

Another reason of concern regarding the pump’s rotor integrity was the presence in the pumping facilities of coarse solid particles. Figure 3 highlights the presence of low velocity domains, a necessary condition for solid particles settling.

The non-uniform flow regime and the low water levels at the inlet in the suction chambers leading to a cavitational operation regime are more susceptible for rotor damages then the presence of coarse solid particles.

To avoid the mentioned drawbacks, several measures for improving the flow structure, namely a uniform distribution at the suction chamber inlet for all five pumps, and increasing the water depth in the suction chambers are necessary.

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