CDA 2008 Annual Conference
Congrès annuel 2008 de l'ACB
Winnipeg, MB, Canada
September 27 to October 2, 2008
du 27 septembre au 2 octobre 2008

POWER INTAKE VELOCITY MODELING USING FLOW 3D AT KELSEY GENERATING STATION

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ABSTRACT:

A hydropower intake is designed in such way to facility the flow to the turbine, to minimize the head loss and to provide the best efficiency of hydraulic machinery. It is generally desirable to maintain as uniform a flow distribution as possible throughout all the intake inlets. The velocity information can be used by the turbine manufacturer to optimize the design of the machinery. A numerical model has been proven as a powerful tool in assisting engineers to investigate the intake velocity distribution.

Manitoba Hydro has initiated a Supply Efficiency Improvement program to update its existing generation station to produce more electricity or to reduce electricity losses in terms of power generation. Kelsey Re-runnering Project was studied and simulated powerhouse intake velocities using FLOW 3D software for all seven units of Kelsey GS under pre and post re-runnering flow conditions are presented in this paper. This information was also used to determine the possible effects on unit power and efficiency due to irregular velocity field entering the intake.

Keywords: Intake, Velocity, FLOW 3D, Modeling

RÉSUMÉ:

Un point de prélèvement hydraulique est conçu de manière à faciliter l'écoulement d'eau vers la turbine afin de réduire la perte de charge et d'optimiser l'efficacité de la machinerie hydraulique. Il est généralement souhaitable de maintenir, dans la mesure du possible, l'uniformité de la distribution de l'écoulement dans toutes les entrées d'eau. Le fabricant de la turbine peut utiliser les données sur la vitesse de l'eau pour optimiser la conception de sa machinerie. Un modèle numérique s'est révélé être un outil de tout premier ordre pour aider les ingénieurs à étudier la distribution de la vitesse de la prise d'eau.

Manitoba Hydro a mis sur pied un programme d'amélioration de l'efficacité (Supply Efficiency Improvement Program) afin de moderniser sa centrale électrique actuelle de façon à augmenter sa production d'électricité ou à réduire les pertes d'électricité relatives à la production d'énergie. On a étudié le projet de remise à niveau de la centrale de Kelsey; ce document présente des simulations des vitesses de la prise d'eau de la centrale pour les sept unités de la centrale hydroélectrique de Kelsey, et ce, en conditions d'écoulement pré-remise à niveau et post-remise à niveau. Ces simulations ont été effectuées au moyen du logiciel tridimensionnel FLOW. Cette information a également servi à déterminer les effets possibles des champs de vitesse irréguliers pénétrant dans la prise d'eau sur la puissance et l'efficacité des unités.

Mots-clés : Prise d'eau, vitesse, FLOW 3D, modélisation

INTRODUCTION

The design of a water resource project requires a deep understanding of the flow characteristics through the hydraulic structure. Numerical modeling usually works as a powerful tool for engineers to quickly and inexpensively explore different design options and demonstrates how a water resource project can be constructed and/or operated more efficiently. In the past, CFD analysis has been extensively used in engineering studies by researchers and engineers (Fuamba, M. 2006, Michael, C. 2006). Manitoba Hydro staffs have used CFD analysis to advance the hydraulic design of many projects for several years. A number of papers have been published so far to present a number of specific design examples (Teklemariam, et al. 2000 & 2002, Groeneveld, et al. 2005, St. Laurent, et al. 2005).

Manitoba Hydro has initiated a Supply Efficiency Improvement program to update its existing generation station to produce more electricity or to reduce electricity losses in terms of power generation. A hydropower intake is designed in such way to facility the flow to the turbine, to minimize the head loss and to provide the best efficiency of hydraulic machinery. It is generally desirable to maintain as uniform a flow distribution as possible throughout all the intake inlets. The intake velocity information is very important for turbine manufacturer to optimize the design of the machinery. FLOW 3D software was used to model the intake velocity at Kelsey Generating Station at Manitoba Hydro under pre and post re-runnering flow conditions. The simulation result is provided to the manufacturer for selecting the suitable turbine. This paper presents the methodology of how to simulate the flow through the powerhouse intake using FLOW 3D software. The powerhouse intake velocities for all seven units of Kelsey GS under pre and post re-runnering flow conditions are also presented in this paper.

KELSEY GENERATING STATION

The Kelsey Generating Station is located as the old Grand Rapids on the Upper Nelson River between Sipiwesk and Split Lake as shown in Figure 1. The plant consisted of 7 units with a capacity of 224 MW in total. The current plant discharge is about 1700 cms, and post rerunnering plant discharge will be 2200 cms. Due to the presence of the rock knob located about 250 m upstream eastside of unit 7, a vertex was formed in the small bay between the rock knob and the powerhouse in the past operation. The efficiency on units 6 and 7 was affected due to the non-uniform approaching flow, the re-runnering of the turbine needs to consider these flow characteristics.

FLOW 3D

The Flow 3D model, developed by Flow Science Incorporated of Los Alamos, New Mexico, USA, is a Computational Fluid Dynamics (CFD) model capable of simulating the dynamic and steady state behavior of liquids and gases in one, two or three dimension. It does so through solution of the complete Navier Stokes equations of fluid dynamics. It is applicable to almost any type of the flow process and capable of simulating free surface flow, and the program utilizes specialized algorithms to track the location of the water surface over large and small spatial and temporal variations. These capabilities make the model well suited for simulating the varied and complex flow conditions, which typically occur in a variety of hydraulic design and analysis problems.

Flow 3D has been extensively used for complex flow simulation in Manitoba Hydro. In this study, it was used to simulate the powerhouse intake flow velocity.

Figure 1: Kelsey Generation Station

MODEL SET UP

The model was setup based on drawings in the Manitoba Hydro drawing management system. The stop log, intake gate guides and trash racks were not modeled. Figure 2 shows the forebay bathymetry and the powerhouse intakes. There are seven units and each unit has three opening to direct the flow to the turbine. The water generally flows to the north as indicated in the Figure 2. Three opening from east to west for each unit are named as opening A, B, C respectively. The coordinate system used in FLOW 3D is indicated as well. Three inter-block meshes are used in the simulation. A finer mesh is setup in the intake to provide detailed velocity information for the turbine manufacturer. A constant water level boundary condition was applied as upstream boundary condition, and the mass sink was setup in the model to simulate the outflow through the power house.

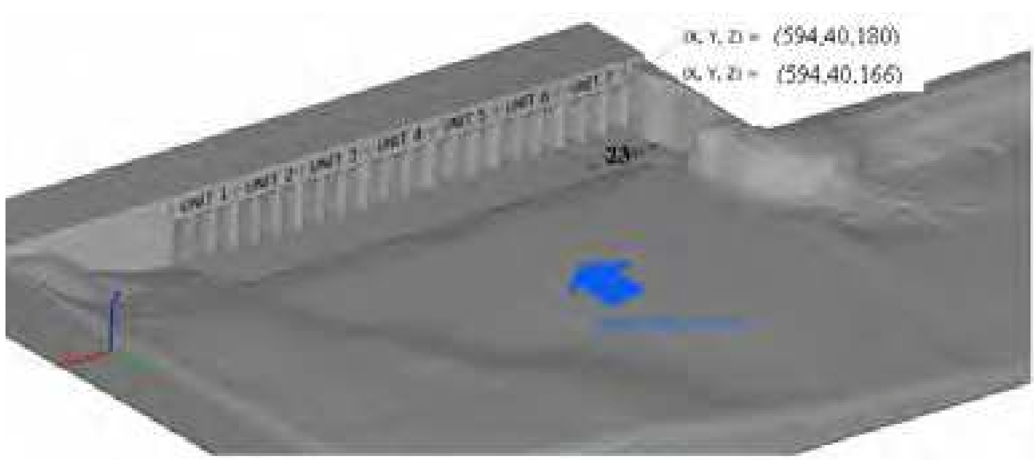

Figure 2: Forebay Bathometry and Intake Layout

MODEL TEST

A few test runs were conducted in order to find a proper way to simulate the outflow from powerhouse. Due to the effect of rock knob, the flow going through each opening of the each unit is quite different, especially for units 6 and 7. At beginning of the test, the seven mass sinks were setup in such a way that each mass sink cross all the three opening. The FLOW 3D automatically split the flow among the three opening. It was found that the flow is not quite properly distributed at each opening for each unit compared to the results from the performance test conducted in 1990.

A mass sink was then setup in each opening to properly model the outflow for each unit. The flow through each unit was split into the three openings with 40%, 36% and 24% of the total flow respectively from wast to east, as indicated in Figure 2. These flow ratios are determined based on the average measured results of units 1 to 5 under full gate operation during turbine performance testing1 in 1990, and then applied to all 7 units. Units 6 and 7 were only tested up to 40%. Table 1 shows the percentage for the flow split.

A velocity distribution for each opening was available for the pre-rerunnering condition at full gate from a 1990's test. Since there is no detailed velocity data, only the three dimensional velocity plots are available. Visual comparison between the FLOW 3D results and field test results indicates that a split in the flow to each opening is a good way to properly model the outflow in FLOW 3D. Visual analysis of the model results shows a close reproduction of field conditions to include a vortex forming in front of units 6 and 7 due to the "rock knob" just upstream, and similar to intake flow fields measured during the metering in 1990.

Table 1: Flow percentage for each opening

Opening	A	B	C
Flow Percentage	40%	36%	24%

MODEL APPLICATION

After the model was tested, it was applied to modeling the following three scenarios since the full gate and best gate flows for the re-runnering case are so similar (ie. 330.5m^3/s/unit vs. 324.1m^3/s/unit),

Case 1: Units 1 to 7 re-runnering (RR) at full gate (FG)
Case 2: Units 1 to 5 re-runnering (RR) at full gate (FG) with units 6 and 7 at existing full gate (FG)
Case 3: Units 1 to 5 re-runnering (RR) at full gate with units 6 and 7 at existing best gate (BG)

The outflow used in the model for each case are presented in Table 2

Table 2: Outflow for each opening for each unit for above three cases

Cases	Unit 1	Unit2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Units 1-7 RR at FG	132.2	132.2	132.2	132.2	132.2	132.2	132.2
	119.0	119.0	119.0	119.0	119.0	119.0	119.0
	79.3	79.3	79.3	79.3	79.3	79.3	79.3
Units 1-5 RR at FG & 6-7 Existing FG	132.2	132.2	132.2	132.2	132.2	97.2	97.2
	119.0	119.0	119.0	119.0	119.0	87.5	87.5
	79.3	79.3	79.3	79.3	79.3	58.3	58.3
Units 1-5 RR at FG & 6-7 Existing BG	132.2	132.2	132.2	132.2	132.2	88.0	88.0
	119.0	119.0	119.0	119.0	119.0	79.2	79.2
	79.3	79.3	79.3	79.3	79.3	52.8	52.8

MODEL RESULTS

Velocity data were extracted for the X-Y plane at the elevation Z=161.5 m and for X-Z section 15m away from intake inlet for three openings of each unit, which was provided to the manufacturer for optimization of turbine design. Some velocity results are presented in Figure 3 to Figure 8.

The results indicate that the velocity distribution is quite different from unit to unit in horizontal (X-Y plane) and vertical plane (X-Z plane) and the difference is even more obvious for unit 6 and unit 7. The reason for the difference is that the outflow through each opening of each unit is forced to be different as result of the rock knob effects

CONCLUSIONS

The FLOW 3D model for Kelsey Intake was setup and successfully used to model the velocity in the intake. This information was provided to the manufacturer and the information has been very useful for optimizing the design of the turbine.

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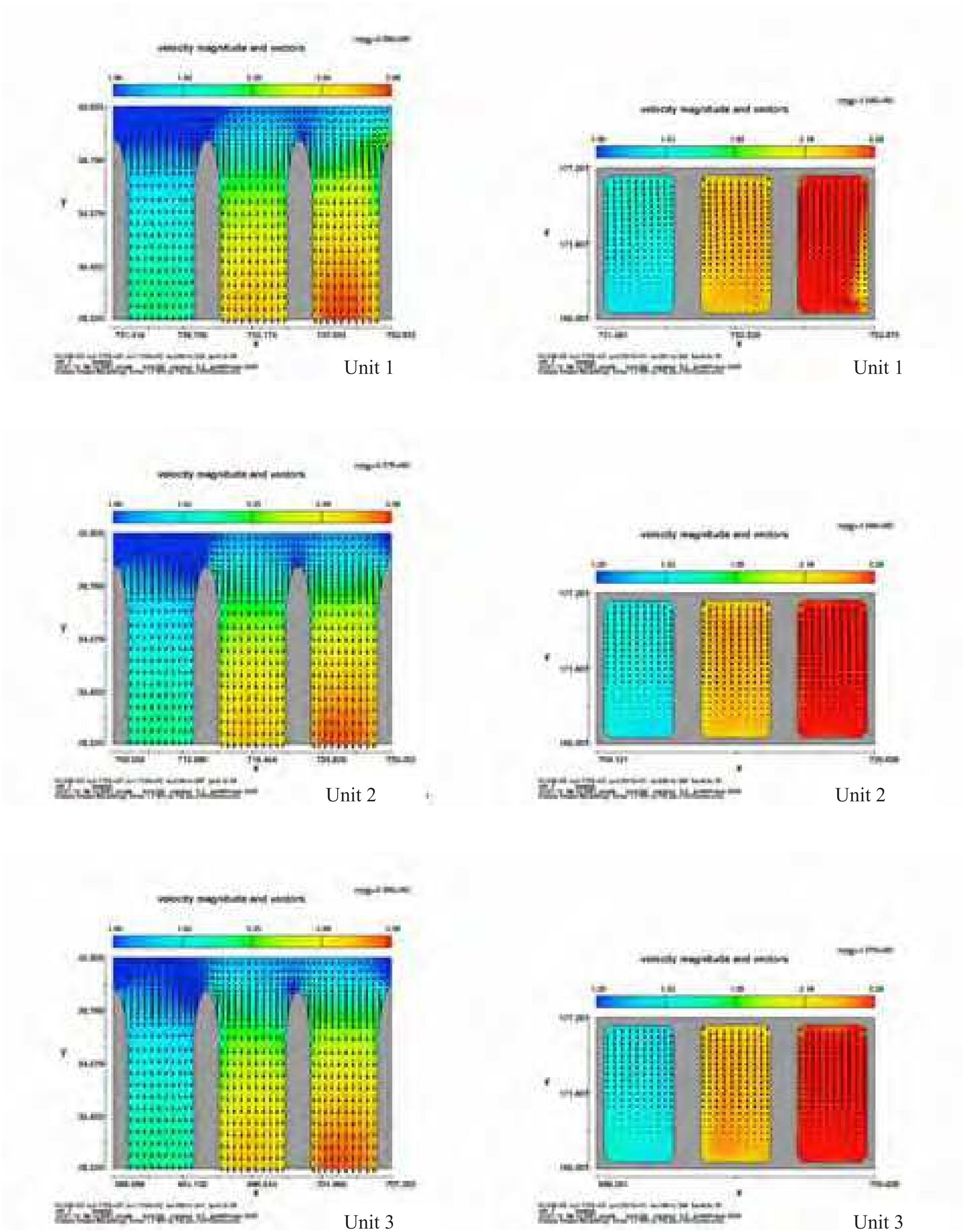


Figure 3: Velocity Distribution from Plan View and Profile View (Case 1)

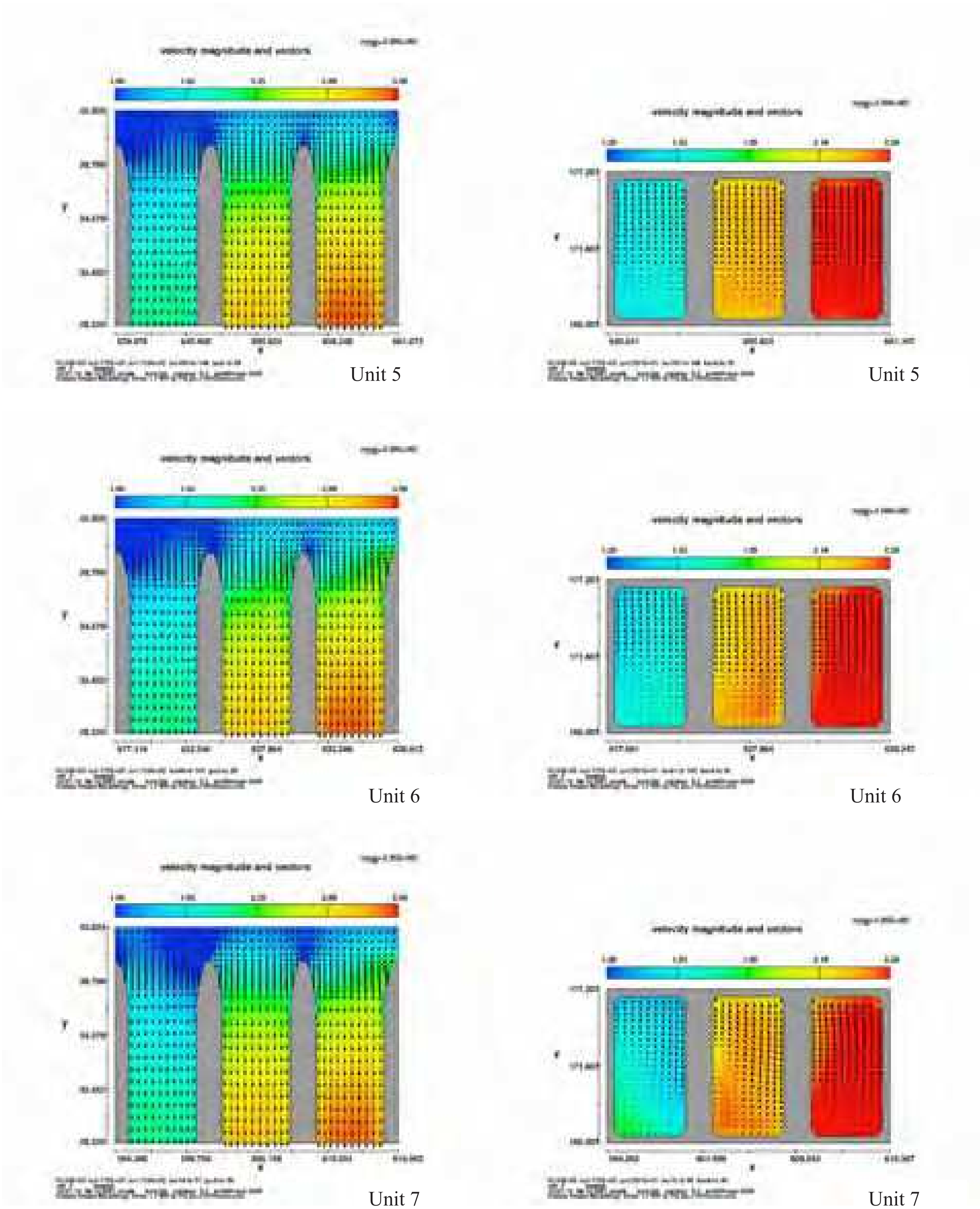


Figure 4: Velocity Distribution from Plan View and Profile View (Case 1)

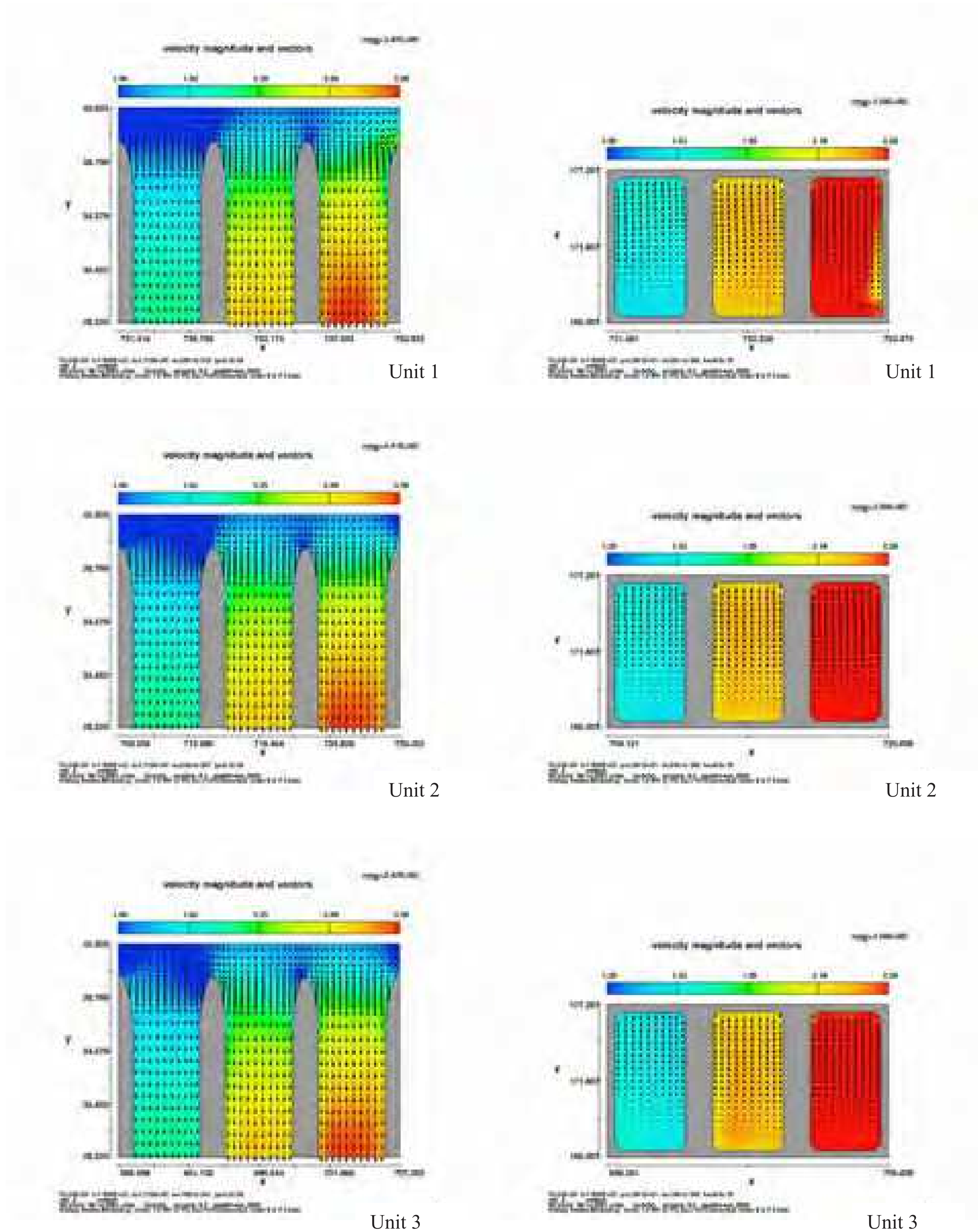
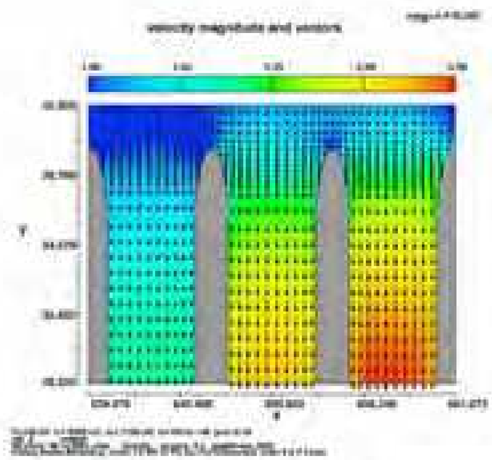
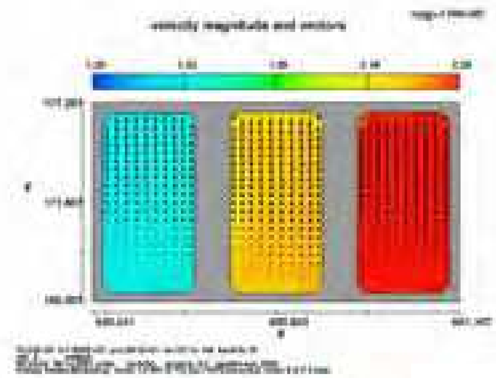


Figure 5: Velocity Distribution from Plan View and Profile View (Case 2)



Unit 5



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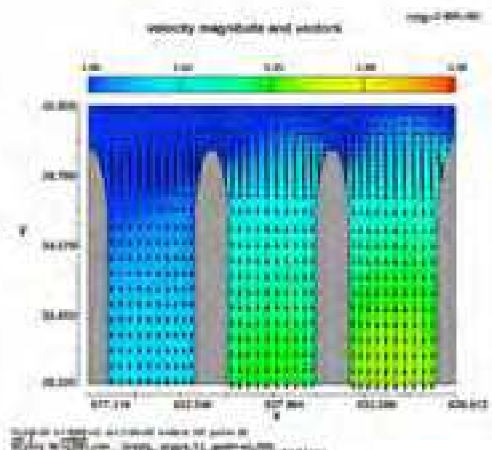

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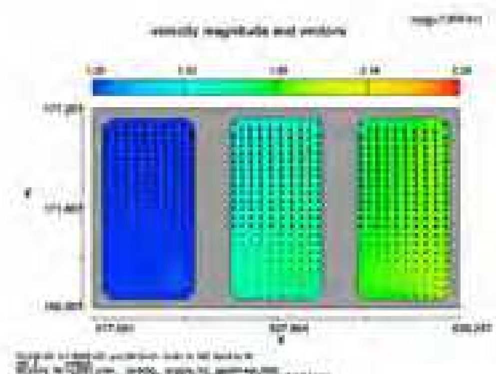

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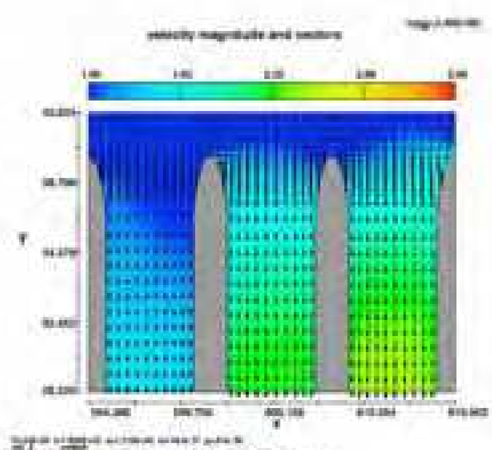

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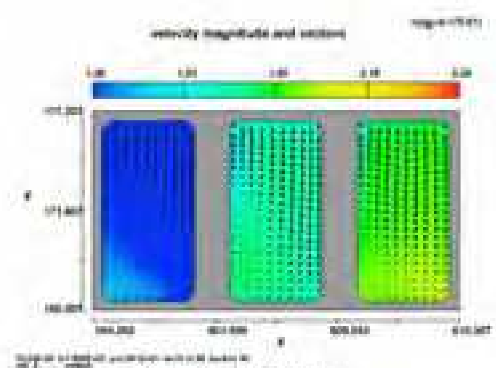

Unit 7

Figure 6: Velocity Distribution from Plan View and Profile View (Case 2)

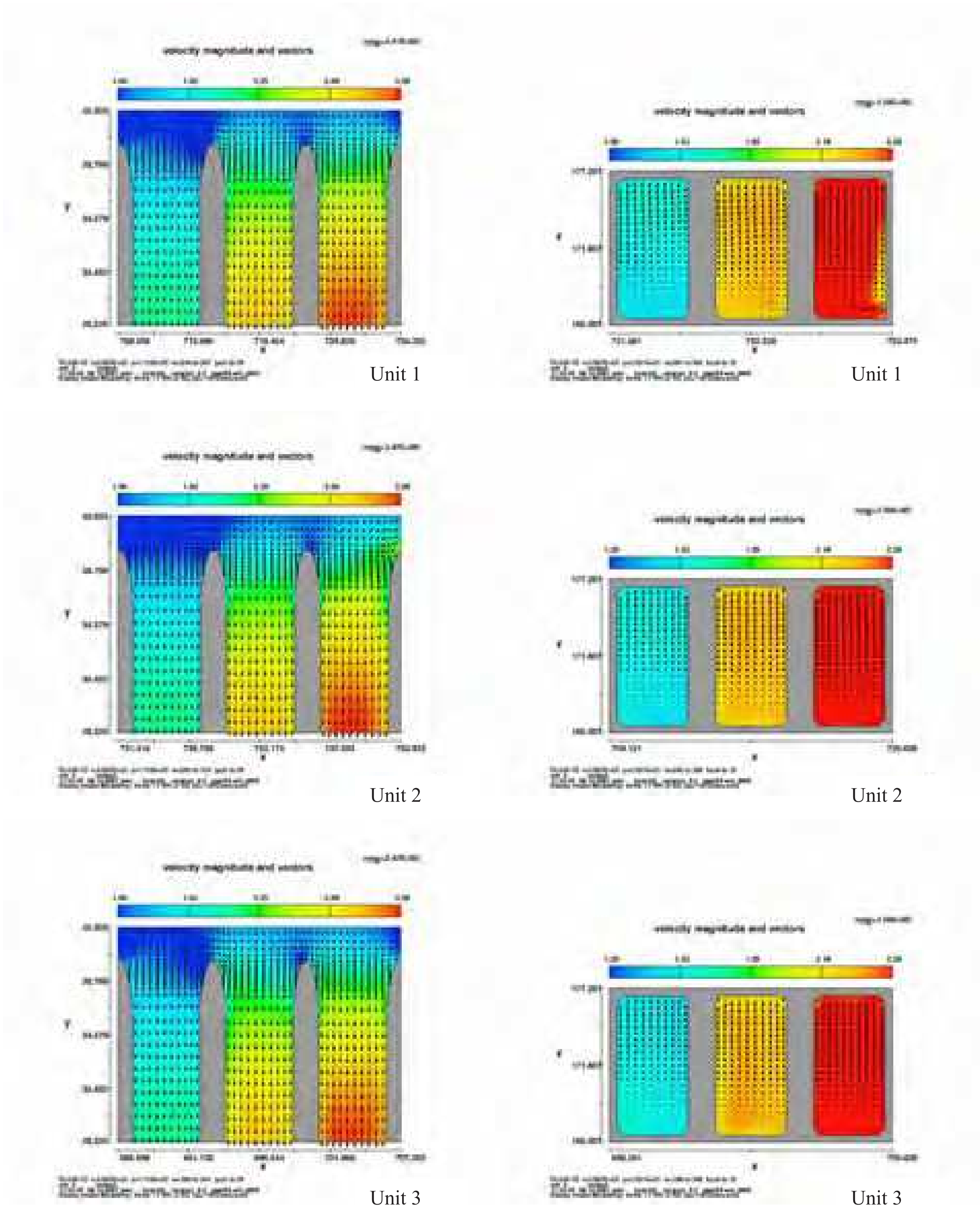

Figure 7: Velocity Distribution from Plan View and Profile View (Case 3)

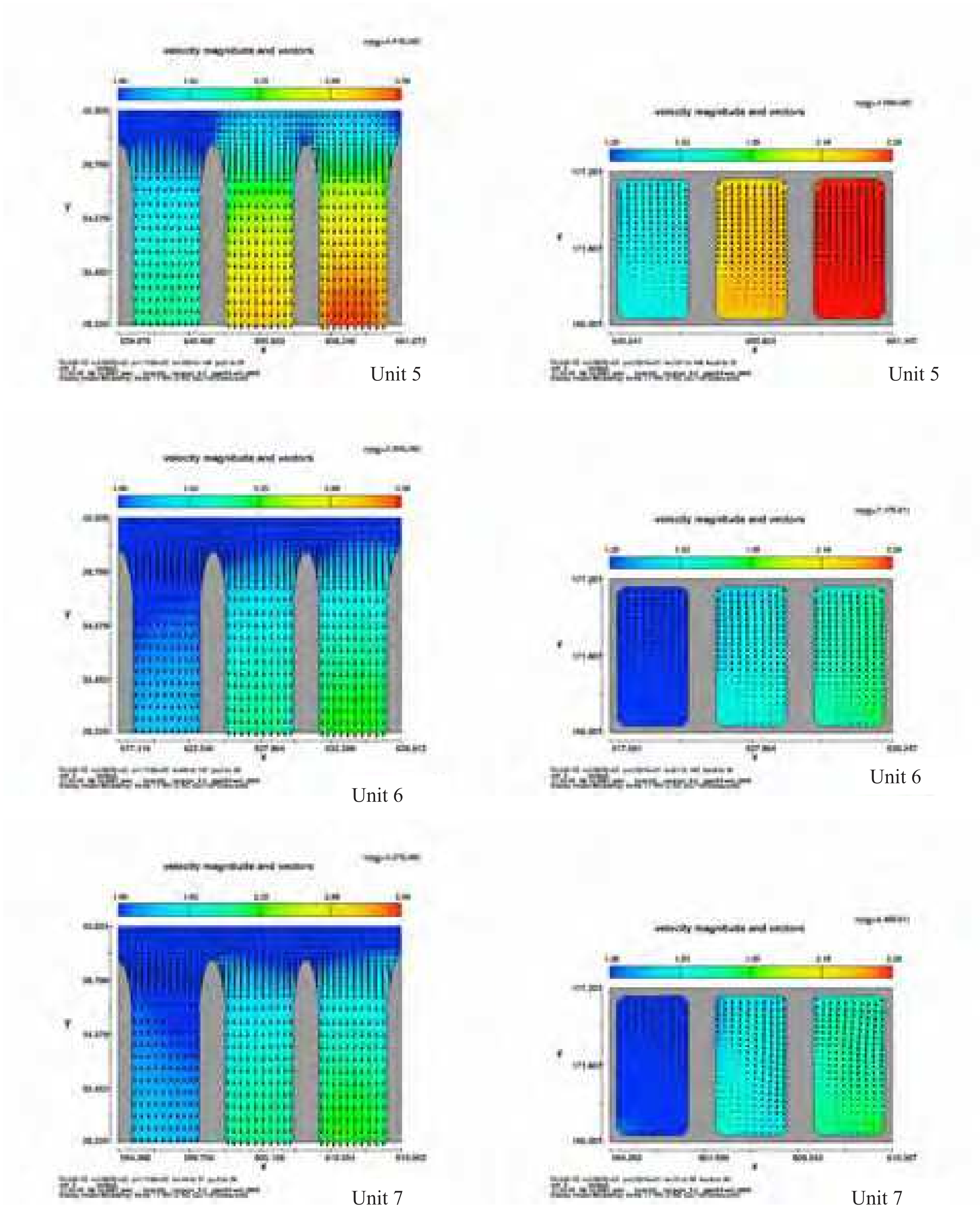

Figure 8: Velocity Distribution from Plan View and Profile View (Case 3)