LABORATORY AND NUMERICAL MODELING OF WATER EXCHANGE IN LONG STRAITS

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Summary In this paper the hydrodynamics of exchange flows is investigated with focusing on the role of non-hydrostatic effects, friction and entrainment in the long straits. The simulation of the exchange flows in a laboratory long and narrow straits were performed with three-dimensional, non-hydrostatic, numerical model of free surface stratified flows. The calculations show importance of entrainment and friction in such flows. As a result the composite Froude number is significantly lower in comparison to predictions of two-layer hydraulic theory.

INTRODUCTION

The internal hydraulics of short and wide straits is the most studied. A concept of maximum exchange was developed for these flows. Recently additional effects such as time dependence, non-hydrostatic effects, mixing and interfacial instabilities which modify two-layer hydraulic theory were studied. The hydrodynamics of water exchange in long straits are less studied. The objective of this study is validation of concept of maximal exchange for long straits.

METHODOLOGY AND RESULTS

The results of laboratory experiment [1] exchange flow through long and narrow strait connecting two deep and wide basins filled with water of different density and the same strait with sill in the middle of the strait [2] are considered and compared with numerical simulations. A buoyancy flux between the two basins was maintained by heating the left basin and cooling the right. The numerical tool for investigations is a three-dimensional, non-hydrostatic, numerical model of free surface stratified flows [3]. The model is a non-hydrostatic extension of the free-surface primitive equation POM model. A mode splitting technique, decomposition of pressure and velocity fields into hydrostatic and non-hydrostatic components are the base of numerical algorithm of the model. A buoyancy flux between the two basins was simulated by including Newtonian relaxation terms in the heat transport equation.

The flow is laminar but experiment data and calculations (Fig. 1 a,b) indicate the presence of a broad thermocline which is evidence of entrainment between the fluid layers. The experiment and computations show (Fig. 2) that composite Froude number G is lower than expected from predictions of two-layer hydraulic theory according to the concept of maximal exchange. The entrainment between layers suggests more complicated structure of flow than two-layer approximation. The computed velocity and density profiles at Fig. 3 show that the flow could be described by the three layer structure with two bounding layers separated by an interfacial layer of finite thickness and variable properties. From Fig. 4 we see that the zero isotach is not centered in the interfacial layer. Fig. 5 shows the role of each layer in carrying the mass. These results demonstrated that the entrainment and friction in this configuration of the long strait is crucial for hydrodynamics and hydraulics of exchange flow in the strait.

The presence of the sill in the middle of the long strait (experiment 701 in [2]) changes the character of the circulation in the strait (Fig. 6, Fig. 8a). The detailed pattern of the velocity field is shown in Fig. 8b. It indicates the presence of a complicated flow structure at the sill zone. The flow slows down at the left side of the sill and then creating a countercurrent. The dense water lifts along the left side of the sill and turns finally to the left, forming a broad interface layer. The broad thermocline is evidence of entrainment between the fluid layers. As well as in the previous experiment the entrainment and friction cause reduction the maximum values of G^2 (Fig. 7). The comparison of non-hydrostatic and hydrostatic calculations was carried out with the same spatial resolution. Fig.8c indicates essential difference between non-hydrostatic and hydrostatic velocity fields. It is about 22% at the slope and the foot of the sill.

CONCLUSIONS

The question about hydraulic control in real long straits like the Bosphorus and Dardanelles is still open. The investigation of the hydrodynamics of the water exchange in the laboratory long straits using 3D non-hydrostatic numerical model demonstrated that the entrainment

Acknowledgments

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References

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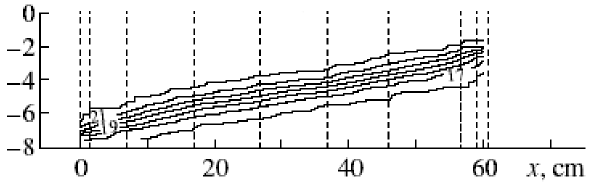
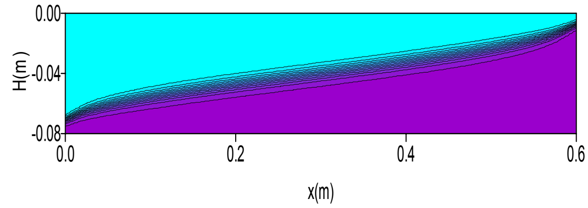
[2] Maderich V. S.: Two-layer exchange flows through long straits with sill. *Oceanic Fronts and Related Phenomena. Konstantin Fedorov Int. Memorial Symp., IOC Workshop Rep. Series*, N 159, UNESCO'2000, 326-331, 2000.

[3] Kanarska Y., Maderich V.: A non-hydrostatic numerical model for calculating free-surface stratified flows. *Ocean Dynamics* 53 No3: 176-185, 2003.



(a)



(b)

Figure 1. Temperature along the strait. (a) measured data, (b) computed results

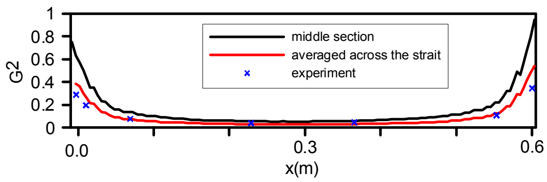


Figure 2. Composite Froude number

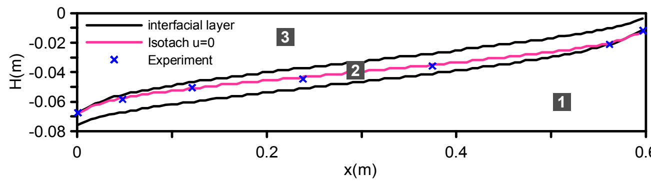


Figure 4. Three layer decomposition

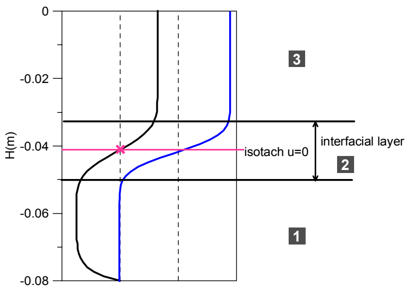


Figure 3. Velocity and density profiles

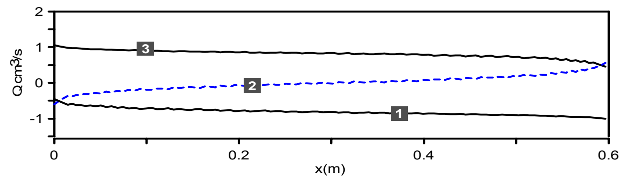


Figure 5. Discharges in each of three layers

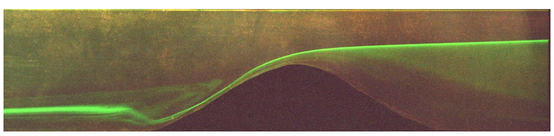


Figure 6. Photo of experiment 701.

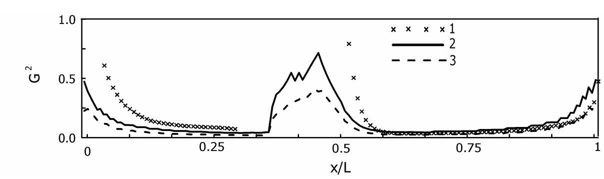


Figure 7. Composite Froude number along the strait calculated from the experiment 701 (1) vs. the computed one in the middle longitudinal section of the strait (2) and computed one using average flow parameters across the strait (3)

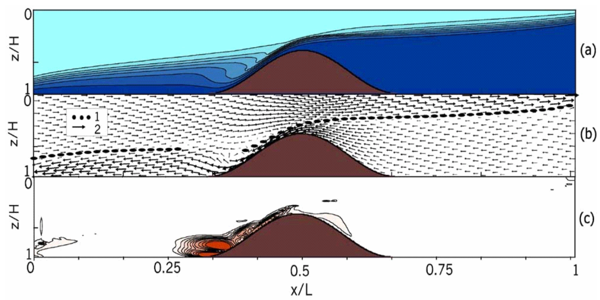


Figure 8. Computed density and velocity fields. (a) Contour plot of computed density from experiment 701. (b) Interface position in experiment 701 (1) and non-hydrostatic velocity field (2). (c) Absolute value of difference between hydrostatic and non-hydrostatic velocity fields.