Flow Control Technology for Enhancement and Diverse Use of the Marine Environment

H. UESHIMA, H. TANABE, M. TAKARADA, I. YUASA, E. HASHIMOTO and M. YAMASAKI
Government Industrial Research Institute, Chugoku, 2-2-2 Hiro-Suehiro, Kure, Hiroshima, 737-01 Japan

In the Seto Inland Sea there exist large-scale red tide and water mass anoxia due to the physical cause of water stagnancy. Our ongoing study aims to establish persistent flow control measures for a tidal basin. In this paper we discuss the possibility of improvement of water mass movements in a tidal basin through topography change and construction measures.

The case studies were carried out with the Seto Inland Sea hydraulic model picking up the Osaka and the Beppu bays. The effects of topography changes at the bay mouth and on the sea floor for Osaka Bay and a dike construction at the bay mouth for Beppu Bay were examined for water mass exchanges, circulations, and mixing and advection of the river water discharged into these bays. These measures effectively alter the balance and patterns of circulations to help improve water movements in the stagnant regions of the basin concerned.

Introduction

Many development projects for Japanese coastal waters are now under planning and execution for urban development on the sea to solve land problems, marine cultivation increase to secure food supplies, and amenity-rich aqua environment creation to accommodate marine leisure and to recover still damaged aqua environments.

For the harmonization of these projects in the Seto Inland Sea, the development of flow control technology is required to repair deteriorated water quality environments and to create appropriate physical flow fields which maximize the diverse use of coastal waters. This is because there still exist large-scale red tides and water mass anoxia in the Seto Inland Sea due to the physical cause of water stagnancy (see Fig.1). Our ongoing study aims to establish robust flow control measures for tidal basins focusing on the relations between tidal residual circulations and water stagnancy.

We will discuss the effect on the basin-indigenous circulation control together with the improvement of water mass movements in stagnant water regions based on the hydraulic experiments with the world's largest physical model of the Seto Inland Sea, as applied to the Osaka and Beppu bays and applying topographic changing and marine structure setting measures.

Seto Inland Sea Hydraulic Model

The world's largest hydraulic model of the Seto Inland Sea was constructed in May 1973 and served studies on dynamics of Inland Sea currents, prediction of effluent diffusion and water mass exchanges of bays and sounds. At present the

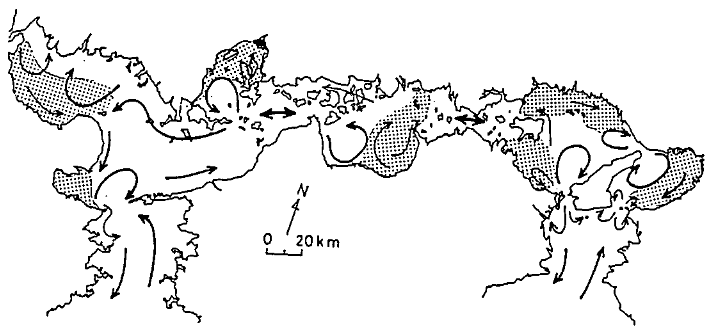

Fig.1 Water stagnant regions (shaded areas) and tidal residual circulations.

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physical model serves the study on persistent current control on a large scale and long term through topographic changes and structure constructions.

The physical model is built on a scale of 1 to 2000 in the horizontal and 1 to 159 in the vertical. The vertical scale is determined as the 2/3 power of the horizontal scale. Froude's law requires the time scale ratio to be 1 to 159. The model measures 230 meters by 100 meters and covers abut 7000 m^2 of water surface. The weir-type tide generating facilities are equipped at three openings and are controlled by computers in the control center.

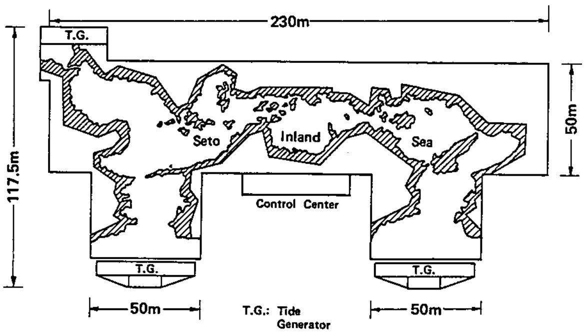


Fig.2 Plan view of the physical model.

Case Studies

The hydraulic transport processes in a tidal basin on a large scale and long term are highly dependent on tidal residual circulations generated by the interaction of basin topography and tidal current. To keep receiving water bodies sound enough for assimilating wastes due to human activities, some active measures are desirable for a persistent current control without artificial energies. Topography changing and structure setting measures are appropriate to this end. Hydraulic model experiments were set up and carried out by measuring currents with floats and velocity meters, and by discharging dyed water from rivers.

Case Study for Osaka Bay

Osaka Bay is a typical semienclosed bay and has two openings. Due to strong tidal currents through the openings, tidal residual circulations A and B are generated as shown in Fig.3. The shaded stagnant water region marked as S is left out of A and B and accompanies a particular circulating flow probably due to the river discharge from R.

The experiment cases (see Fig.4) were set up by closure of minor straits and removal of islands on the line XY in Fig. 3. The percentage of cross section on XY is 100%, 93%, 89% and 146% respectively for Case 0, 1,2 and 3. Figure 5(a) shows representative water trajectories obtained by float monitoring for 10 tidal periods with one period intervals (same figures were also obtained for Case 2 and 3). The closure of straits in Case 1 increases the transfer distance of the water started from point B as much as twice of that in Case 0. The closure of straits in Case 2 makes the region of circulation A shift southeasterly and changes greatly circulation B. The removal of islands in Case 3 almost extinguishes circulation B and pushes the region of circulation A up north. These topography changes alter the circulation balance of A and B, as well as the water

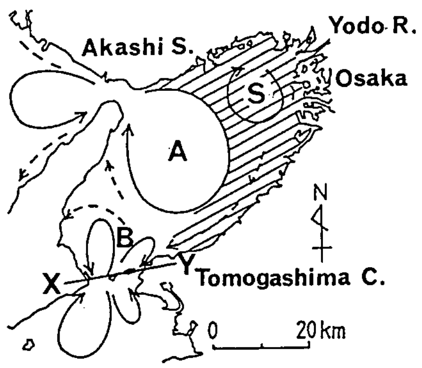


Fig.3 Current conditions in Osaka Bay.

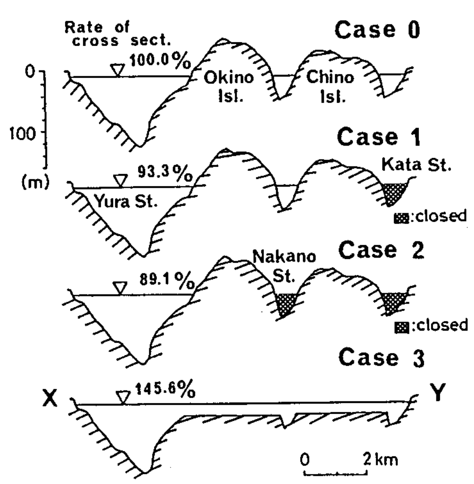
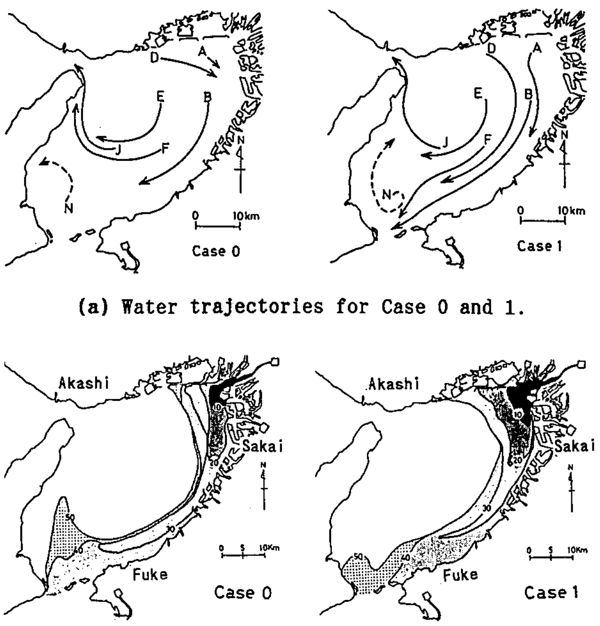


Fig.4 Experiment cases for bay mouth change.

movements in the stagnant regions, which is reflected in the river water spreading as shown in Fig.5(b), where the front of the dyed river water at each ten tidal periods is sketched. The water residence time for the stagnant region was also examined and, compared with that of Case 0, is improved most in Case 3, and to a lesser extent in Case 1, but worsened in Case 2.

As for bay bottom topography changes a trench cutting measure was applied. The experiment cases are shown in Fig.6. Trench A is planned to introduce waters of circulation A, trench B to increase flushing waters from region S and trench C to enhance vertical mixing of the river water discharged from river R. Figure 7(a) is the result for case 3, with fronts of dyed river water from R (compare with the figure of Case 0 in Fig.5(b)). The spreading area of the river water after 50 tidal periods for Case 3 extends as much as 1.4 times of that for Case 3, which suggests improvement on water movements from stagnancy. Figure 7(b) shows water trajectories obtained by float monitoring for 10 tidal periods with one period intervals. Circulation A increases its strength and shifts its position up north as the number of trenches increase.



(a) Water trajectories for Case 0 and 1.

(b) River water spreading for Case 0 and 1.

Fig.5 Experiment results on bay mouth change.

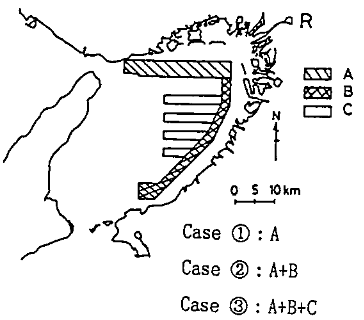
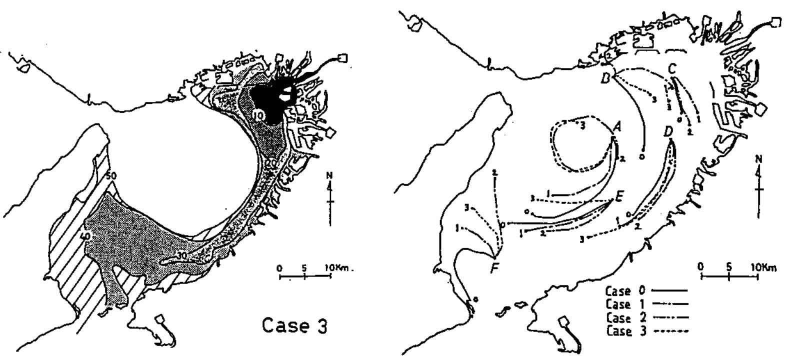


Fig.6 Experiment cases for bay bottom change.



(a) River water front spreading for Case 3.

(b) Water trajectory changes for Case 0,1,2,3.

Fig.7 Experiment results on bay bottom change.

Case Study for Beppu Bay

As shown in Fig.8 Beppu Bay is a typical open bay of cavity type and is exposed to outside tidal residual circulation a. In the bay there exist Moffatt's vortex-like circulations, b and c, abruptly decreasing their speeds. The stagnant water region coincides with the region of circulation c. The dike setting is supposed to be a proper measure to change water movements in the stagnant region. This is because circulation a primarily governs circulations b and c. The experimental cases were set up according to each numeral of thick lines denoting dike setting positions.

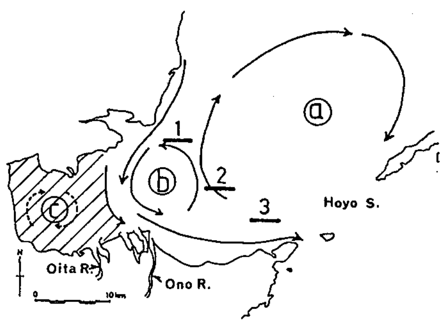


Fig.8 Current conditions in Beppu Bay.

Experiment results are shown in Figs. 9 and 10. In case 0 the river water from r_1 and r_2 in one direction penetrates the inner bay due to circulation c, and in the other direction progresses easterly due to circulation b. The dike setting for Case 1 enlarges westerly the region of b and makes all river water flow out easterly along the coast. The dike setting for Case 2 strengthens circulation c and makes a portion of discharged river water swiftly penetrate the inner bay. For Case 3, in contrast, the dike setting almost extinguishes circulation b and reverses the circulation direction of c, which is the cause of northward flowing-out of the river water. The water exchange rate of a basin concerned can be roughly estimated by a float dispersion method. The method consists of releasing floats initially placed uniformly in the basin as shown in Fig.10(a) and counting the number of floats remaining in the basin. As shown in Fig.10(b), the dike setting at the bay mouth helps improve the water exchange between inside and outside waters of Beppu Bay.

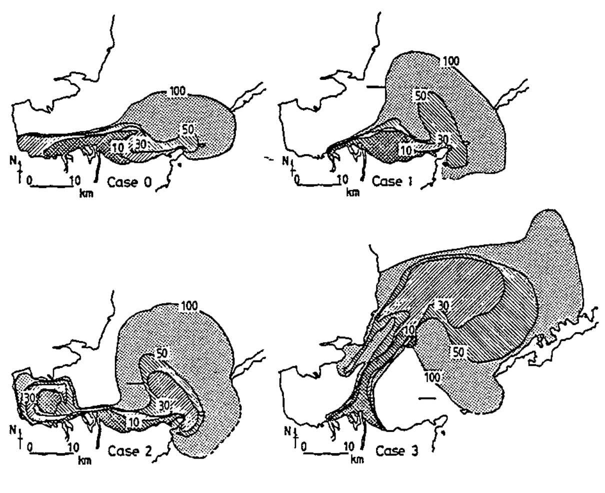
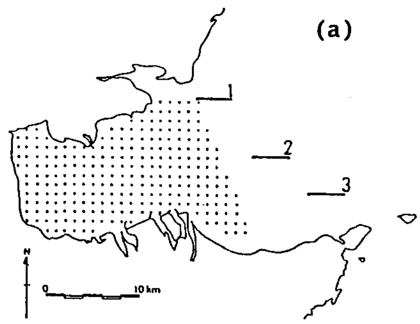
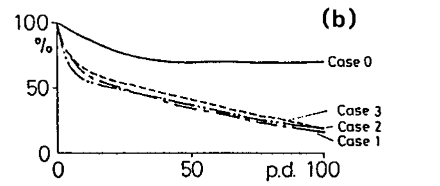


Fig.9 Changes of river water spreading.



(a) Initial distribution of floats.



(b) Rate changes of remaining floats.

Fig.10 Water mass exchange results.

Conclusion

To realize the diverse and active use of coastal waters of the Seto Inland Sea, it is necessary not only to establish the concept for "fitting" necessary developments into the natural environment, but also to develop required technology realizing such concepts. One of the key technologies is a current control technology without artificial energies in which a persistent current control is realized in a large scale and long term. This is because the hydraulic transport processes in the Seto Inland Sea are highly dependent on tidal residual circulations.

Topography changing and structure setting measures are appropriate for such current control. From the case studies on Osaka Bay and Beppu Bay with the Seto Inland Sea hydraulic model, we have confirmed the effectiveness of those measures both on water exchange improvement in stagnant regions and on mixing and advection of river water discharged there.

To harmonize the diverse use of coastal waters and the maintenance of an amenity-rich aqua environment, it is not a mere subject in coastal engineering, but a wider subject of global environment management and maintenance. Further studies at international and interdisciplinary levels are recommended for current control technology on coastal waters.