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Image Processing Techniques for Flow Patterns in the Seto Inland Sea Hydraulic Model

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Various flow visualization techniques were applied to study the tidal exchange of the Seto Inland Sea with the largest hydraulic model in a horizontal scale 1/2000. To analyze dyefront patterns, image processing techniques have been developed. The techniques include the extraction of the boundary of the dyefront and the flow direction through tuft images.

Key Words : Tuft Flow Visualization, Dye Visualization, Seto Inland Sea Hydraulic Model

1. INTRODUCTION

The Seto Inland Sea of Japan, surrounded by dense pollution and well developed industrial area, still awaits for a further development and, therefore, calls for a large-scaled water quality management study. To prepare for the future development, it is required to study measures not only to check a deterioration of water quality but to create a desirable water quality environment based on understanding of water mass exchange characteristics[1).

In order to evaluate water exchange characteristics, it is necessary to extract quantitative information about flow behaviors of tidally driven currents. This paper deals with the experiments using the hydraulic model of the Seto Inland Sea, one of the largest. The model simulates tide and tidal currents in the Seto Inland Sea[2). In the model, a dye visualization method and a tuft flow visualization method are employed. These visualized patterns are recorded on the color slide films in the constant time intervals. Image processing techniques have been developed to analyze visualization films. And then dyefront velocity distributions in the hydraulic model are determined[3)-4).

2. SETO INLAND SEA HYDRAULIC MODEL

The model is built in the scale ratios of 1 to 2000 and 1 to 159 in the horizontal and vertical directions, respectively. The model measures 230 meters by 50 meters and covers about 7000m² of water surface. The model is equipped with three tide generators at each of three openings of the sea to the outside oceans. Fig. 1 shows Seto Inland Sea hydraulic model and Fig. 2 shows its plane view. The model includes seventy-three river

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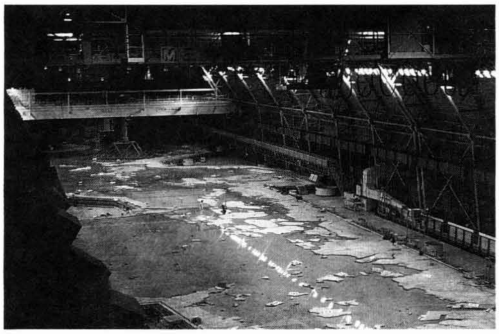

Fig. 1. Seto Inland Sea Hydraulic Model

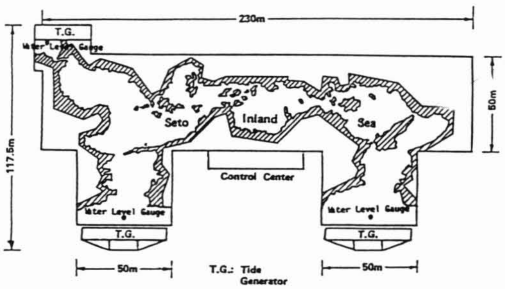

Fig. 2. Plane view of Seto Inland Sea Hydraulic Model

flow generating facilities which can discharge regulated flows mixed with dye sollutions of rhodamine-B simulating pollutant loads.

3. IMAGE ANALYSIS FOR DYEFRONT PATTERNS

1) Image Data Acquisition

Image data are taken by using a color drum-scanner, and digitized into 256 levels at an 512 × 512 array of points for each the red, green and blue color components.

2) Tuft Flow Visualization

The basis of the method is the use of extremely thin nylon monofilament for the tufts, the process of attaching them to the small bar on the ground of the hydraulic model, and the use of photography for recording the tuft patterns. A number of tufts patterns are obtained without affecting the flow as shown in Fig. 3. By the region segmentation[2], the boundary of a tuft is detected as shown in Fig. 4. Similarly, the boundaries of a number of tufts are extracted. By the bilinear interpolation of the four neighbours, as shown in Fig. 5, the flow direction at M point can be expressed as

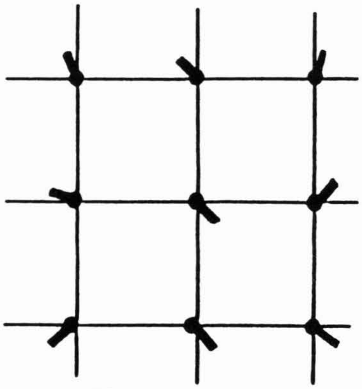

Fig. 3. Tuft images

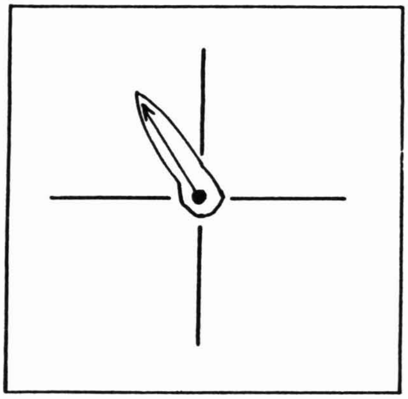

Fig. 4. Boundary of a tuft

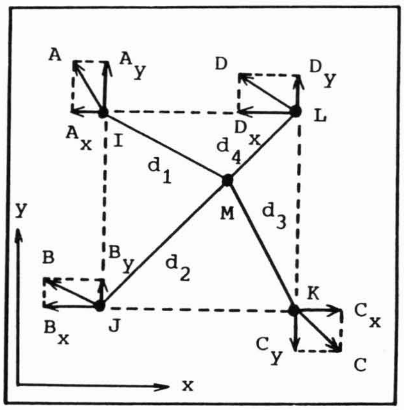

Fig. 5. Interpolation of the flow direction

$$E_x = \frac{\frac{A_x}{d_1} + \frac{B_x}{d_2} + \frac{C_x}{d_3} + \frac{D_x}{d_4}}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4}} \quad (1)$$

$$E_y = \frac{\frac{A_y}{d_1} + \frac{B_y}{d_2} + \frac{C_y}{d_3} + \frac{D_y}{d_4}}{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4}} \quad (2)$$

3) Slug-dye Visualization

Slug-dye release experiments are conducted in the model. Dyefront patterns in the model are recorded on the color slide films in the constant time intervals. And then the boundaries of the dyefront pattern are extracted by the region segmentation[2)]

4) Calculation of Dyefront Velocity Distributions

Let the dyefront be the contour 1 of Fig. 6

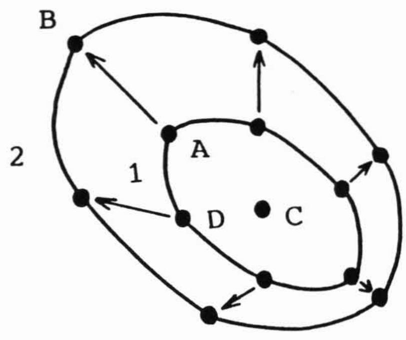

Fig. 6. Dyefront velocity distributions

and the new dyefront after passage of a very short time be the contour 2. We calculate the coordinates of the center of the gravity and the perimeters of the contour line at each time. And the contour line 1 is divided by N points so that they start with D point at the same horizontal line of C. At each point on the contour 1, flow directions are determined by using equations (1) and (2). The dyefront velocity at point A is represented by the rate of displacement of the dyefront in the same direction obtained by the tuft method to the next contour 2. Similarly, dye-front velocity distributions at each point of the contour 1 are determined. Thus, dyefront velocity distributions at each time are obtained.

4. EXPERIMENTAL RESULTS

Fig. 7 shows the image at the slug-dye release time (t = 0s). Figs. 8 and 9 show a red band image of Fig. 7 and a green band image of Fig. 7, respectively. Fig. 8 shows the background and Fig. 9 shows the slug-dye at t = 0s. After performing image data subtraction (R-G), the region segmentation is applied to the data. Thus, the region of the dyefront pattern at t = 0s is detected as shown in Fig. 10. Similarly, the region of the dyefront pattern at t = 28.2s is detected as shown in Fig. 11. After a geometric transformation, two boundaries at t = 0s and 28.2s are overlayed with the image of Fig. 10, as shown in Fig. 12. From this figure, it becomes clear that the dyefront is propagated in the direction of the tidal circulating flow. Figs. 13, 14,

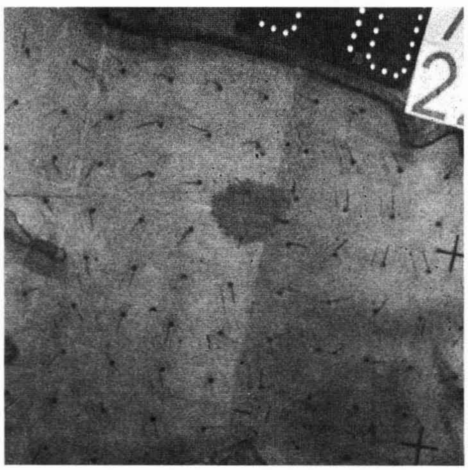

Fig. 7. Image at t = 0s

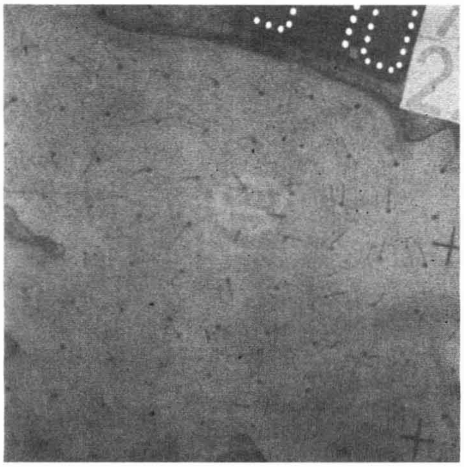

Fig. 8. Background at t = 0s

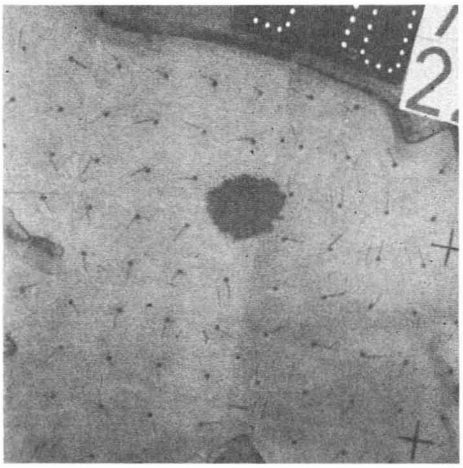

Fig. 9. Dyefront pattern at t = 0s

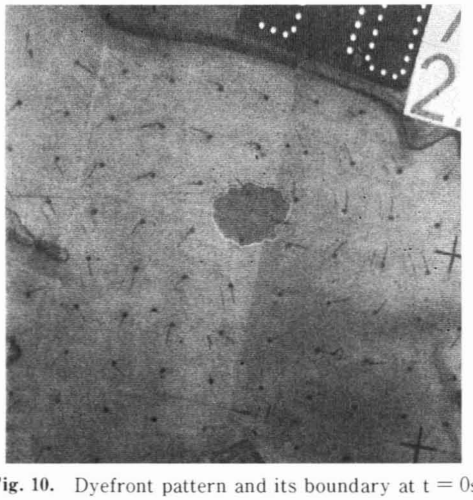

Fig. 10. Dyefront pattern and its boundary at t = 0s

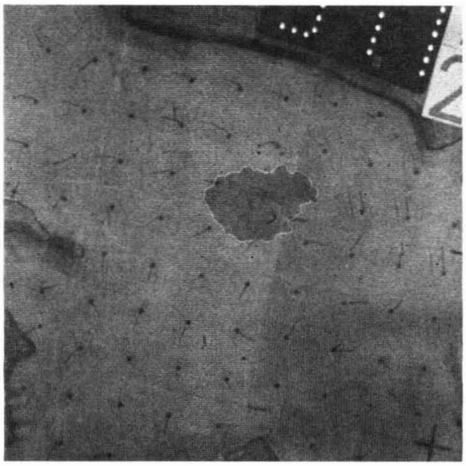

Fig. 11. Dyefront pattern and its boundary at t = 28.2s

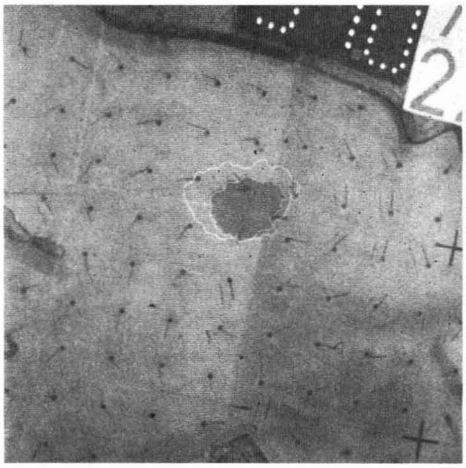

Fig. 12. Detected boundaries at t = 0s and t = 28.2s

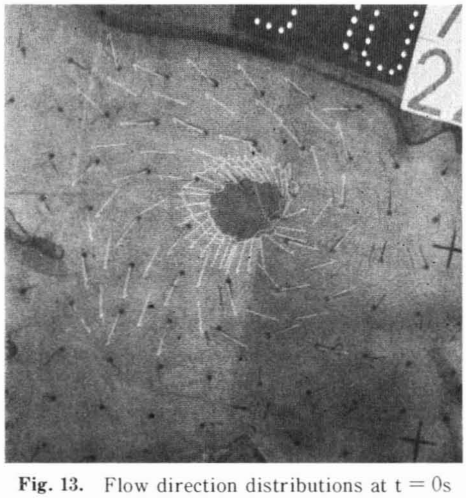

Fig. 13. Flow direction distributions at t = 0s

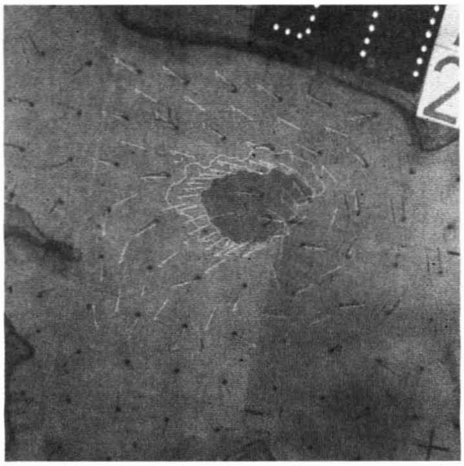

Fig. 14. Flow direction distributions at t = 28.2s

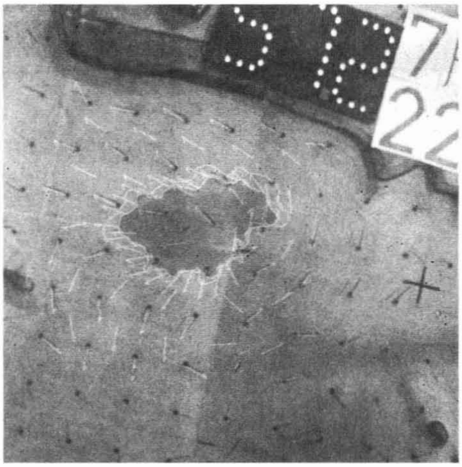

Fig. 15. Flow direction distributions at t = 56.4s

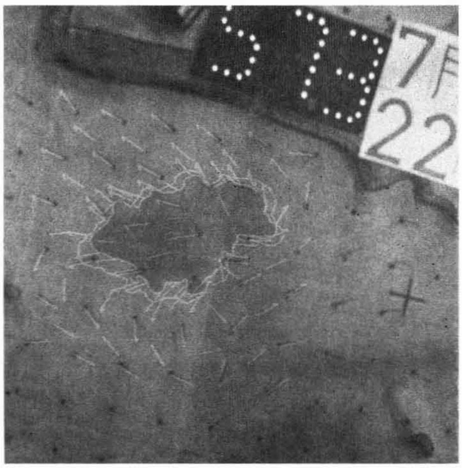

Fig. 16. Flow direction distributions at t = 84.6s

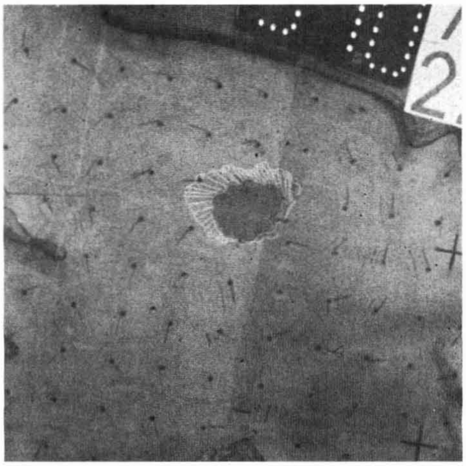

Fig. 17. Flow velocity distributions at t = 0s

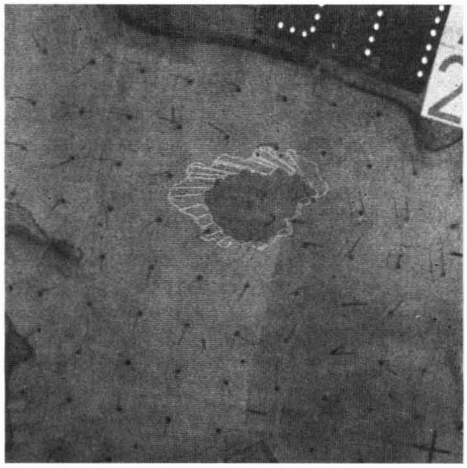

Fig. 18. Flow velocity distributions at t = 28.2s

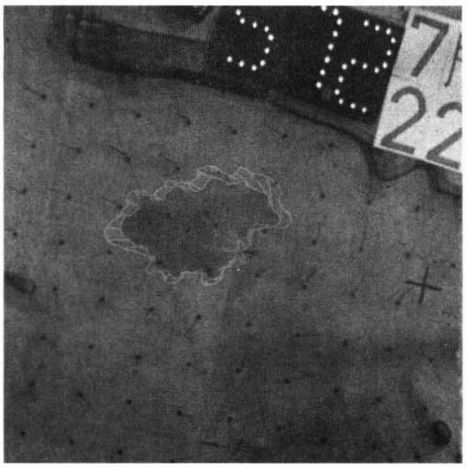

Fig. 19. Flow velocity distributions at t = 56.4s

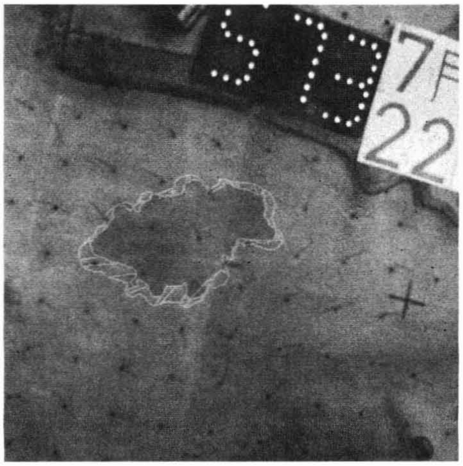

Fig. 20. Flow velocity distributions at t = 84.6s

15 and 16 show the flow direction distributions obtained by the tuft method. Figs. 17, 18, 19 and 20 show the dyefront velocity distributions at each time.

5. CONCLUSIONS

As a result of this study, the following conclusions have been obtained.

(1) The front boundaries of the dyefront patterns are precisely extracted by image processing techniques.

(2) From the results of slug-dye release experiments and experiments with tufts, it becomes clear that the dyefront velocity distributions are obtained quantitatively.

(3) The method presented in this study may be useful to evaluate the water exchange characteristics in the Seto Inland Sea.

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要　　約

近年，瀬戸内海地域では，過去の産業発展や人口増加に伴って発生した水質汚濁も改善されてきており，将来に向けた海の積極的利用が模索されている。水質汚濁シミュレーションを行うために建設された瀬戸内海大型水理模型も，こうした動きの中で，人為的な流動環境操作法に基づく海の有効利用を図るための手段として活用される方向にある。このような海域流動環境の制御効果を評価するためには，物質輸送に関わる流れを的確に捉えることが必要である。

最近のコンピュータや画像処理技術の発達に伴って，流れの可視化で得た画像から流れの定量的な情報を求める研究が進められている。これらの研究においては，可視化手法としてトレーサ直接注入法を用いて個々のトレーサ粒子あるいはトレーサ粒子群の移動から流速ベクトル分布が求められている。

筆者らはさきに瀬戸内海大型水理模型内に放流した染料の拡がりを検出するための画像処理手法について報告した。本論文では，染料とタフトを併用した可視化手法により経時的に一定間隔で得られた一連の流れパターンから，水理模型の広島県呉湾での流速ベクトル分布を求める画像解析手法と結果について述べる。

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