Estimation of flow in a rearing tank of marine fish larvae by simplified numerical computation?a case of two-dimensional flow

Shiotani, Shigeaki

Hagiwara, Atsushi

Sakakura, Yoshitaka

Chuda, Hisashi

(Citation)
Aquacultural Engineering,32(3-4):465-481

(Issue Date)
2005-04

(Resource Type)
journal article

(Version)
Accepted Manuscript

(URL)
https://hdl.handle.net/20.500.14094/90000474

Estimation of Flow in a Rearing Tank of Marine Fish Larvae by Simplified Numerical Computation
-A Case of Two-dimensional Flow-

Shigeaki Shiotani,[1] Atsushi Hagiwara,[2] Yoshitaka Sakakura,[3]
Hisashi Chuda[4]

[1*] Faculty of Maritime Sciences, Kobe University,
5-1-1 Fukae-Minami, Higashinada, Kobe 658-0022, Japan
Tel. & Fax: 81-78-431-6241
E-mail: shiotani@maritime.kobe-u.ac.jp

[2] Graduate School of Science and Technology, Nagasaki University,
1-14 Bunkyo-Machi, Nagasaki 852-8521, Japan
Tel. & Fax: 81-958-819-2830
E-mail: hagiwara@net.nagasaki-u.ac.jp

[3] Faculty of Fisheries, Nagasaki University,
1-14 Bunkyo-Machi, Nagasaki 852-8521, Japan
Tel.: 81-958-819-2823; Fax: 81-958-819-2799
E-mail: sakakura@net.nagasaki-u.ac.jp

[4] Nagasaki Prefectural Fisheries Experimental Station, Nagasaki
1551-4 Taira-Machi, Nagasaki 851-2213, Japan
Tel.: 81-958-850-6312; Tel.: 81-958-850-6359
E-mail: chuda@marinelabo.nagasaki.nagasaki.jp

"The affiliation of author designated #1 is listed below."
The complete postal address is listed below.

Shigeaki Shiotani
Faculty of Maritime Sciences, Kobe University,
5-1-1 Fukae-Minami, Higashinada, Kobe 658-0022, Japan
Tel. & Fax: 81-78-431-6241
E-mail: shiotani@maritime.kobe-u.ac.jp

Abstract

Marine fish larvae are fragile against physical stress. However, few studies have been conducted to evaluate the flow field in a rearing tank, which is assumed to provide a high degree of physical stress to marine fish larvae. The flow field in a rearing tank (volume of 1 m^3) is generated by aerators, which are commonly used to provide oxygen.

This paper is a report on the estimation of stationary flow in the rearing tank of marine fish larvae. The larvae are seven band grouper larvae of *Epinephelus septemfasciatus*, which have a very low survival rate immediately after the hatching of eggs. The experiments of rearing of seven band grouper larvae were carried out using rearing tanks with four aeration rates (1000, 200, 50 ml/min, and no aeration). The effects of aeration on the survival and floating death of seven band grouper larvae were examined. The experiments confirmed that the mass mortality of seven band grouper larvae depends on the flow rate in the rearing tank. Aeration at 200 ml/min resulted in the highest survival and growth rates of grouper larvae.

Larvae-rearing experiments provided evidence that the flow rates of the rearing tanks are very important design aspects of rearing tanks. The estimation of flow in a rearing tank for an aerating rate of 200 ml/min was carried out by numerical calculation. The computation was simplified by a two-dimensional flow based on experimental results. The calculated flow in the rearing tank was compared with the experimental one. The calculation of the stationary flow in the rearing tank showed good qualitative and quantitative agreement with the experimental results. The numerical estimation of the flow in a rearing tank of marine fish larvae was confirmed to be effective and satisfactory for the design of a tank that would provide optimum performance.

Key words: *Epinephelus septemfasciatus*, Larval rearing tank, Flow field, Numerical computation

1. Introduction

The culturing of marine fish larvae is in an era of rapid progress and significant improvement. However, marine fish larvae are fragile against physical stress, such as unfavorable flow, light, and temperature conditions, which may result in the mass mortality of larvae. Among fish species, grouper larvae are highly sensitive to physical stress, and mass mortality is caused by flotation in the rearing tank after the hatching of eggs (Masuda et al., 2001). The flow in a rearing tank was assumed to have the greatest impact of any condition on small grouper larvae. The flow in a rearing tank is usually generated by aerators that commonly provide oxygen and evenly distribute live food. However, few studies have been conducted on the flow field in the rearing tank (Backhurst and Harker, 1988). Yamaoka et al. (2000) reported that air bubbles produced during aeration caused mass mortality as a result of flotation. In addition, the idea that death can be caused by floating needs to be explained here and elsewhere. Shiotani et al. (2003) attempted a series of systematic experiments in which stationary flow was measured in 1 m^3 polyethylene rearing tanks for seven band grouper *Epinephelus septemfasciatus.*

The experiments of rearing seven band grouper larvae were carried out using rearing tanks (1 m^3 polyethylene tank) with four aeration rates (1000, 200, 50 ml/min, and no aeration). A spherical aerator was set at the bottom center of the tank to generate the flow in the tank. The effects of aeration on the survival and floating death of seven band grouper larvae were examined by counting the number of dead larvae floating in the tank. Rearing experiments were used to confirm that the flow depended on the mass mortality of seven band grouper larvae. Aeration at 200 ml/min produced the highest survival and growth of grouper larvae.

Measurements of stationary flow in a rearing tank identical to those used in rearing experiments were made using an aeration rate of 200 ml/min. The results of the study indicated that the stationary flow in the rearing tank was vertical and the horizontal circulation was unremarkable. However, a considerable amount of time was required to measure the flow in the rearing tank. In addition, since the optimum stationary flow varies for each kind of larvae, the measurement of the flow for each kind of larvae is impractical in terms of time and economy.

Therefore, the development of a method for estimating the stationary flow in a rearing tank that could be used instead of a flow meter would be significant for the examination of larva growth and mass mortality caused by flotation. The estimation of stationary flow in a rearing tank for marine fish larvae was carried out using a numerical computational method. However, there have been few studies on the evaluation of the flow field in rearing tanks. The numerical computational method is a finite differential scheme of the Marker and Cell (MAC) type. The calculation method for estimating the stationary flow field in the rearing tank was simplified in the early stages of our research. The flow in a rearing tank was calculated two-dimensionally based on experimental results of the measuring of flow. The calculations of the flow were compared to the results obtained from experimental conditions with an aeration rate of 200 ml/min, which produced the best survival rates for rearing seven band grouper *Epinephelus septemfasciatus*, using a 1 m^3 polyethylene rearing tank.

The simplified method of calculation was satisfactory for determining the stationary flow and velocity in the rearing tank; the method compared favorably to the results obtained in the experiments.

The results from these studies may be very useful for estimating the stationary flow in a rearing tank and for designing tanks that will be good for rearing larvae.

2. Materials and Methods

2.1. Experiments of rearing larvae

For investigating the effects of flow in a rearing tank on mass mortality in the initial stage after hatching of seven band grouper *Epinephelus septemfasciatus*, experiments of rearing larvae were conducted. Four aeration rates were proposed for the experiments of rearing larvae. A total of 20,000 of grouper larvae were reared in a 1 m^3 polyethylene tank, as shown in Fig. 1, at each aeration rate. The flow in the rearing tank was generated with a typical spherical aerator with a diameter of 5 cm placed at the bottom center of the rearing tank. The rearing tank was cylindrical with a 154 cm diameter at the top and a height of 82 cm.

The numbers of dead larvae on the water surface in the tank were counted everyday. The survival rate of larvae was estimated by counting the number of larvae in the unit water volume sampled at random. The experiment of rearing larvae was carried out until 9 days after the eggs hatched. The results of rearing experiments were compared under each set of different aerating rate, in addition, the effects of the various aeration rates on survival and larva deaths, according to the number dead and floating, were investigated.

2.2. Measurements of flow

In second, the measurements of stationary flow by aerating in the rearing tank generated by an aeration were carried under the condition of the rearing rate at 200 ml/min gave the highest survival and growth of grouper larvae. In addition, the rearing-tank flow caused by aeration was measured at 200 ml/min, the rate which produced the best survival and growth results. It was possible to adjust the position for measuring in the x, y, and z directions with the traverse installed in the flow meter. The flow in the rearing tank was measured at each positions in the half plane of vertical section included the center of water tank. The mean velocities of three components (u, v, w) of flow in the rearing tank were obtained from sampling data. The time for sampling the flow was 0.1 s, and the sample continued for 50 s.

2.3. Numerical estimation of flow

For the purpose of estimating the stationary flow in the rearing tank, a numerical computation was conducted at 200 ml/min, the condition that produced the best results. The vertical circulation was superior to the horizontal one; thus, a numerical computation of two-dimensional flows was carried out in the measured section of the tank for simplification. The non-dimensional governing equations were the three-dimensional incompressible Navier-Stokes equations (1, 2 and 3) and the continuity equation (4) by the cylindrical coordinates system for the circular tank as follows:

$$\frac{\partial v_r}{\partial t}+v_z\frac{\partial v_r}{\partial z}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta^2}{r}=-\frac{\partial p}{\partial r}+\frac{1}{\mathrm{Re}}\left(\nabla^2 v_r-\frac{v_r}{r^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}\right) \quad (1)$$

$$\frac{\partial v_\theta}{\partial t}+v_z\frac{\partial v_\theta}{\partial z}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r v_\theta}{r}=-\frac{1}{r}\frac{\partial p}{\partial \theta}+\frac{1}{\mathrm{Re}}\left(\nabla^2 v_\theta-\frac{v_\theta}{r^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}\right) \quad (2)$$

$$\frac{\partial v_z}{\partial t}+v_z\frac{\partial v_z}{\partial z}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}=-\frac{\partial p}{\partial z}+\frac{1}{\mathrm{Re}}\nabla^2 v_z \quad (3)$$

$$\frac{\partial v_z}{\partial z}+\frac{\partial v_r}{\partial r}+\frac{v_r}{r}+\frac{1}{r}\frac{\partial v_\theta}{\partial \theta}=0 \quad (4)$$

where

$$\nabla^2=\frac{\partial^2}{\partial z^2}+\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2}{\partial \theta^2} \quad (5)$$

where the origin in the cylindrical coordinates system was placed on a free water surface at the center of rearing water tank, and (r, θ, z) represented the axis in radial, circular and upward directions, respectively. The velocity components were (v_r, v_θ, v_z), p was the pressure in the water, including the static pressure component considering the acceleration of gravity, Re was the Reynolds number.

In the case of measurement of flow in the rearing tank, the Cartesian coordinates system of (x, y, z) was defined. The relation between the cylindrical coordinates system and the Cartesian coordinates system can be written as follows:

$$x=r\cos\theta, \qquad y=r\sin\theta, \qquad z=z \quad (6)$$

However, the velocity components (u, v, w) of the Cartesian coordinates system on the two-dimensional measured vertical section coincide with (v_r, v_θ, v_z) of the cylindrical coordinate, because the flow was symmetry to vertical line on the center of the rearing tank.

The calculation of the flow in the rearing tank was made by the finite differential method using a MAC scheme. The time differentials in Eqs. (1), (2) and (3) were expressed by the first-order forward difference, namely the Euler explicit scheme. The second-order central differences were used for the spatial differentials in Eqs. (1), (2), (3), and (4). Keeping the numerical computation stable, the convection terms were evaluated by the third-order upstream difference. The Poisson equation for obtaining the pressure term was solved by the SOR method.

The grid topology of the calculated region in the rearing water is shown in Fig. 2. The computational domain was approximated to rectangular of $0.0 \leq r \leq$ side wall and bottom of rearing tank $\leq z \leq$ free water surface. The radius of the water tank was 69.9 cm on a free surface, and the water depth was 68 cm, in agreement with the experimental rearing tank. The number of grid points was 25×25 in the (r, z) directions, and the grid spacing was regular. A staggered mesh was used. The minimum spacing of the grid near the water wall was relatively large because the main objective of the computation was to simulate a stationary flow in the rearing tank, and the more detailed flow in the boundary layer near the wall was not necessary at the present time. In the future, the calculation of a more detailed flow near the wall and at the free surface of the rearing tank will be arranged.

Boundary conditions in the computational domain were as follows. On the bottom and sidewall boundaries, the no-slip condition was implemented. At the center of the rearing tank boundary, the mean flow obtained from the measured flow was implemented because the relation between the aeration rate and the distribution of the flow velocity was not fully known. On the free water surface condition, it was assumed that the free surface elevation was fixed and the velocity component of w was zero, because the weak aerating rate was not almost caused the variation of the free surface elevation.

The Reynolds number based on the diameter of rearing tank and the strongest mean velocity generated by aerating on the center line in the rearing tank was about 1.0×10^5 order, and was 1.0×10^4~1.0×10^3 order in other measured region. The computation of turbulent flow in the column of air bubbles was very difficult and complex for the liquid-gas two-phase flow. Because the object of this research in the first step was the simulation of the stationary flow in the rearing tank, the computation of flow in the rearing tank was made by assuming the laminar flow, and the turbulence model was not included in the basic equations for the simplified numerical computation. The computation began with zero velocity and continued throughout the entire domain until a steady flow was achieved.

The effect of flow by the geometric profile of the rearing tank was examined. The flow velocities created by an aerator on the center vertical lines of these rearing tanks were assumed constant value. The flows were calculated in three kinds of rectangular rearing tanks in which the ratios of half width to water depth (B/2)/d were 1.0/1.0, 2.0/0.5, and 0.5/2.0 with constant two-dimensional areas with the same volumes. The velocity distributions of flow in the rearing tank were compared. The mean velocity components in the rearing tank and the variable coefficients of flow velocity as defined by Eqs. (7) and (9) were also compared.

$$\overline{V} = \frac{\sum_{i=1}^{n} V_i}{n} \tag{7}$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n} \left(V_i - \overline{V}\right)}{n}} \tag{8}$$

$$Coef = \frac{SD}{\overline{V}} \tag{9}$$

where V_i is the velocity strength of the steady flow at each measured position in the water tank ($V_i = \sqrt{u_i^2 + v_i^2}$), $\overline{V}$, the mean flow velocity in the rearing tank, n, the number of calculated data, SD, the standard deviation of the flow velocity, and $coef$, the variable coefficients of the flow velocity.

3. Results

3.1. Effects of aeration in Rearing experiments

The effects of aeration rates in the rearing experiment on the percentage of surviving larvae of *Epinephelus septemfasciatus* are shown in Fig. 3. The highest survival rate of larvae was 59.8% in the initial stage after the hatching of eggs in tanks with an aeration rate of 200 ml/min. No aeration indicated the lowest survival rate of 17.5% at 9 days after the hatching of eggs; the strongest aeration rate of 1000 ml/min resulted in an 18.1% survival rate, and an aeration rate of 50 ml/min resulted in a survival rate of 37.8%.

Fig. 4 shows the effects of the aeration rate on the floating death of *Epinephelus septemfasciatus* larvae in the rearing experiment. The number of floating deaths at the initial stage after the hatching of eggs increased in the following order depending on the aeration rate: 1000 ml/min, no aeration, 50 ml/min, and 200 ml/min.

The survival of larvae was very high in the initial stage after the hatching of eggs in tanks with an aeration rate at 200 ml/min. Dissolved oxygen level in the rearing tank ranged from 6 to 8 mg/l.

3.2. Experimental flow by aeration in the rearing tank

The velocity distribution under the best of conditions for rearing larvae, with an aeration rate of 200 ml/min, is shown in Fig. 5. The upper figure shows the *u*-*w* velocity distribution on the measured vertical section, and the lower shows the *v*-*w* velocity distribution. In the *u*-*w* velocity distribution, remarkable vertical circulation was observed; however, in the *v*-*w* velocity distribution, the flow was not regular, and the *v* velocity component was very small. This indicates that there was almost no horizontal circulating flow in the rearing tank. Therefore, it was concluded that the flow in the rearing tank was two-dimensional in the vertical section.

3.3. Comparison of experimental and calculated flow

Fig. 6 shows the calculated flow velocity distribution in the rearing tank under the best condition (an aerating rate of 200 ml/min) obtained during the larva-rearing experiment. The remarkable vertical stationary circulating flow in the computational section was similar to the experimental result shown in Fig. 5. The center of the circulation flow in the experimental result appears to be located at approximately x = 45 cm and z = -25 cm. On the other hand, the position in the calculated results was $x(=r)$ = 46 cm and z = -26 cm. On the whole, the calculated stationary flow was very similar to that obtained in the experimental results.

The calculated flow was partially compared with the experimental one in detail. Fig. 7 shows a comparison of calculated and experimental velocity distributions on the vertical and the horizontal lines including the center of vertical circulating flow in the rearing tank. In the figure, the black marks show the experimental velocity components *u, w* and the velocity strength *V*, and the white marks show the calculated results. The abscissa is the velocity of flow, and the vertical axis is the depth *z*. In the figure, on the vertical line, the experimental and calculated *V* approach zero near z = -25 cm, and both flow directions of the *u* velocity components change. Point *z* is the center of the vertical circulating flow. The flow profiles of *V* were very similar to each other. On the horizontal line, though the strong upward flow of *w* velocity component near the center of the rearing tank due to aerating, the flow of the other position was very weak.

A comparison of the calculated and experimental velocity distributions on the vertical center line of the rearing water tank is shown in Fig. 8. Both the *V* and *w* components were remarkably large due to the upward flow by aeration, and both u velocity components were very weak, except near the free surface. The experimental velocity component *w* was very similar to the calculated one, resulting in almost uniform flow.

Fig. 9 shows a comparison of the calculated and experimental velocity distributions under a free water surface. The upper figure shows flow under a free surface at the water depth of about z = -1.0 cm and the lower figure shows one of z = -3.0 cm. In the upper figure, the experimental *u* velocity component near the center of the rearing tank was stronger than the calculated one. The calculated small *w* velocities components near the center of the rearing tank due to the boundary condition of the fixed free surface in the calculation. However, both velocities were very similar in the lower figure.

A comparison of calculated and experimental velocity distributions on the vertical line about 5 cm from the side wall is shown in Fig. 10. Both strengths of flow were reduced by the wall boundary. In the experimental results, even though the *u* and *w* velocity components became very small negative values, a week downward flow was observed. In the calculated results, the v_r (= *u*) velocity component was almost zero, and the v_z (= *w*) velocity component in the upper layer in the rearing tank became negative for a downward flow. The v_z (= *w*) velocity component in the lower layer decreased, and the flow stagnated for a no-slip condition on the side wall and the bottom.

3.4. Effects of flow to different tank profile

Fig. 11 shows two kinds of grid topologies of a different tank profile with a ratio of (B/2)/d at 4.0 and 0.25. Fig. 2 indicated a ratio of (B/2)/d at about 1.0. They had the same volumes. The numbers of grid points were 25 × 50 and 50 × 25, respectively.

The calculated distribution of the stream velocity in the two kinds of rearing tanks shown in Fig. 11 is shown in Fig. 12. In the figure of *(B/2)/d* = 0.5/2.0, a small vertical circulation was observed in the upper layer of a deeper rearing tank. On the other hand, a large vertical circulation was observed at the biased position on the side wall in a shallower rearing tank.

Fig. 13 shows the mean value of the total flow velocity in the calculated vertical section in the rearing tank, as shown in Eq. (7), as well as the experimental one. The results obtained in the experiments were larger than those obtained from calculations in the case of a (*B*/2)/d ratio equal to 1.0.

The calculated and experimental variable coefficients of flow, as shown in Eq. (9), are shown in Fig. 14. For the calculated and experimental results, both coefficients of the *u* component were larger than other coefficients, and the calculated result was larger than the experimental result. The results in the case of (*B*/2)/d equal to 1.0 were the smallest.

4. Discussion

An aeration rate of 200 ml/min, as shown in Fig. 3, produced the highest percentage of survivors of *Epinephelus septemfasciatus* larvae in the rearing experiment. When the aeration rate exceeded 200 ml/min, the rapid velocity of the flow created significant physical stress for the small fish larvae. When the aerating rate was below 200 ml/min, there was no water movement in the central area of the vertical circulation flow, and a region of stagnant water was created. This water area probably did not receive direct supply of oxygen from the aerator, which may have affected the physiological status of larvae distribution in the area. This water area in the rearing tank was polluted and the water environment for larvae became worse. An appropriate flow velocity seems to be required to create suitable conditions for the rearing and feeding of larvae.

The effect of aeration on the floating death of *Epinephelus septemfasciatus* larvae was the smallest in the rearing experiment with an aeration rate of 200 ml/min, as shown in Fig. 4. Dissolved oxygen level in the rearing tank ranged from 6 to 8 mg/l, which was enough quantity to maintain the fish condition. When the aeration exceeded 200 ml/min, a strong vertical circulation and many air bubbles were generated. As a result, the chance of direct physical damage to the larvae increased. When the aeration was below 200 ml/min, the direct supply of oxygen from the aerator was reduced, as reported above. Therefore, the mortality of the larvae was significantly increased, and many larvae floated to the top of the tank.

After the rearing experiments, it was concluded that the flow in the rearing tank significantly affected the survival and growth of grouper larvae and that the aeration rate of 200 ml/min produced the best survival and growth rates.

From the measured results of flow velocity distribution generated by aeration in the rearing tank, it was confirmed that the remarkable vertical circulating flow in *u* and *w* velocity components was created on the measured vertical section; however, and that the horizontal circulating flow in *u* and *v* velocity components was not created and the *v* flow velocity component was very small. It is confirmed that an aerator placed at the bottom center of the rearing tank created the upward flow with air bubble, the radiated horizontal flow under the free water surface toward side wall from the center of tank, downward flow near the side wall and horizontal flow near the bottom toward the center of rearing tank from the side wall in rearing tank. This suggests that two-dimensional calculations can be used to estimate the flow on the vertical section in the rearing tank, including the center of the tank. A comparison of the experimental and calculated results indicates that the simplified computational method herein presented can be used to satisfactorily represent the stationary vertical circulating flow. The calculated and experimental positions of the center of the vertical circulating flow were very similar. The velocity distributions on the vertical and horizontal lines, including the center of the circulating flow, are in good agreement.

Comparing Fig.5 and Fig.6, both profiles of the vertical circulating flow were very similar from the position of center of circulation flow qualitatively or quantitatively. Especially, from the comparison of calculated and experimental velocity distributions on the vertical and horizontal lines including the center of vertical circulation in the rearing tank as shown in Fig.7, both velocity distribution were very similar quantitatively.

The two-dimensional velocity distributions (u, w) = (v_r, v_z) between the experimental and calculated results were compared in detail. As shown in Fig. 8, in the numerical calculation, the boundary condition implemented on the vertical center line indicates satisfactory velocity distribution as compared with the experimental result. From Fig. 7, the calculated v_r velocity component distribution near the center region under a free water surface in the tank was smaller than the experimental one, and both results were discrepancy. As the boundary condition of a free water surface was fixed such as a solid wall, the improvement of free surface boundary condition considering a moving free surface in real will be demanded. This problem will be improved in the future. The calculated flow velocity distribution near the sidewall was in very good agreement with the experimental one, as shown in Fig. 10. The numerical simulation of the flow field in the rearing tank was quite satisfactory, both quantitatively and qualitatively, in comparisons with the experimental results.

The mean velocity in the rearing tank means the speed of larvae transported by flow, and the variable coefficient means a degree of fluctuating speed of the moving larvae. The experimental mean velocities were larger than the calculated results, as shown in Fig. 13, because the number of experimental data was not so much than the data from the calculations, and the data of flow velocity which was reduced by the wall of the rearing tank could not be measured and was not included in Eq.(7). The mean values of V and w (= v_z) indicated the tendency to be inversely proportional to $(B/2)/d$ and, the mean velocity u (= v_r) was small in general. Because the center vertical line was long became and then the mean value of the strong upward velocity distributions on the vertical line increased in the case of small ratio $(B/2)/d$.

In Fig. 14, the variable coefficients of the u velocity component were larger in all cases, and those of the w velocity components were smaller. As the variable coefficients of V, u (= v_r) and w (= v_z) were the smallest in the case of a $(B/2)/d$ of 1.0, a tank of $(B/2)/d$ = 1.0 seems suitable to prevent damage to larvae by variation of flow.

Though it is not clear which the mean velocity or the variable coefficient of velocity largely impacts damage to larvae in the initial stage after hatching of eggs, the shape of the rearing tank affected to flow field. In the future, the larvae rearing experiments using rearing tanks of different shape will be planned in detail.

This paper reports the initial result of the mathematical models employed to investigate the cause of larval stress reared in the rearing tanks. The first phase of the calculation analyzes the flow in the tank using two-dimensional model by Cartesian coordinate systems. Using this model we were able to simulate the two-dimensional stationary flow inside the tank. In addition to this model, a model using the cylindrical coordinates system was also applied. Both models showed quite similar results. Utilizing the same tank used in the present experiment, and with the assumption that larvae were randomly distributed in the rearing tank and their specific gravity is the same as the rearing water and they move along with the stationary flow, larvae will be exposed to the turbulence flow in the column of air bubbles about 200 times a day in 1 m^3 tank. We can deduce that turbulence flow due to aeration caused significant stress to the fish larvae. The described turbulence flow is made up of slight and complicated flows, and its analysis is important in the next phase of this research.

5. Conclusion

The numerical computation for estimation of viscous stationary flow generated by an aerator in the rearing tank was carried out. The numerical computational method is the simplified two-dimensional finite differential scheme based on the Navier-Stokes equation. The calculated results were compared with the experimental results. Furthermore, the effect of the profile of the rearing water tank on the flow field is examined by numerical simulations.

The main conclusions of this study are summarized as follows:

1. The effect of the aeration rate on the floating death of *Epinephelus septemfasciatus* larvae in the rearing experiment was the smallest when an aeration rate of 200 ml/min was used.
2. Remarkable vertical circulation was observed on the measured vertical section; however, almost no horizontal circulating flow was generated in the rearing tank.
3. The vertical circulating flow in the rearing tank obtained through the experiment was simulated satisfactorily by the simplified numerical computation proposed in the present paper.
4. The calculated stationary flow was in good agreement, both quantitatively and qualitatively, with the experimental results.
5. The improvement of boundary condition on free water surface was demanded for the estimation of flow under near free water surface with higher accuracy.
6. The mean velocity in the rearing tank indicated the inverse to proportion to $(B/2)/d$ related to the shape of rearing tank.
7. The variable coefficient in the rearing tank indicated that the degree of variation of the flow was the smallest in the case of $(B/2)/d$ of 1.0.
8. In the future, the design of the rearing tank will be planned for the purpose of obtaining the optimum environmental flow for marine fish larvae, and examinations of rearing of larvae will be carried out.

Acknowledgements

This study was supported by a grant from the Prefectural Collaboration of Regional Entities for the Advancement of Technological Excellence, JST. The authors express their thanks to Lena H. Asano Helen S. Marcial for reviewing the manuscript.

References

Backhurst, J.R., Harker, J.H., 1988. Suspension of feed in aerated rearing tanks: effect of tank geometry and aerator design. *Aquaculture Engineering* **7,** 379-395.

Masuda, R., Ziemann, D.A., Ostrowski, A.C., 2001. Patchiness formation and development of schooling behavior in pacific threadfin *Polydactylus sexfilis* reared with different dietary highly unsaturated fatty acid contents. *Journal of the World Aquaculture Society* **32,** 309-316.

Shiotani, S., Akazawa, A., Sakakura Y., Chuda H., Arakawa T., Hagiwara A., 2003. Measurements of flow field in a rearing tank of marine fish larvae: a case study of the seven band grouper *Epinephelus septemfasciatus*. *Fisheries Engineering* **39(3)**, 201-208.

Yamaoka, K., Nanbu, T., Miyagawa, M., Issiki, T., Kusaka, A., 2000. Water surface tension-related deaths in pre larval red seven band grouper. *Aquaculture* **189,** 165-176.

List of Figures and Tables

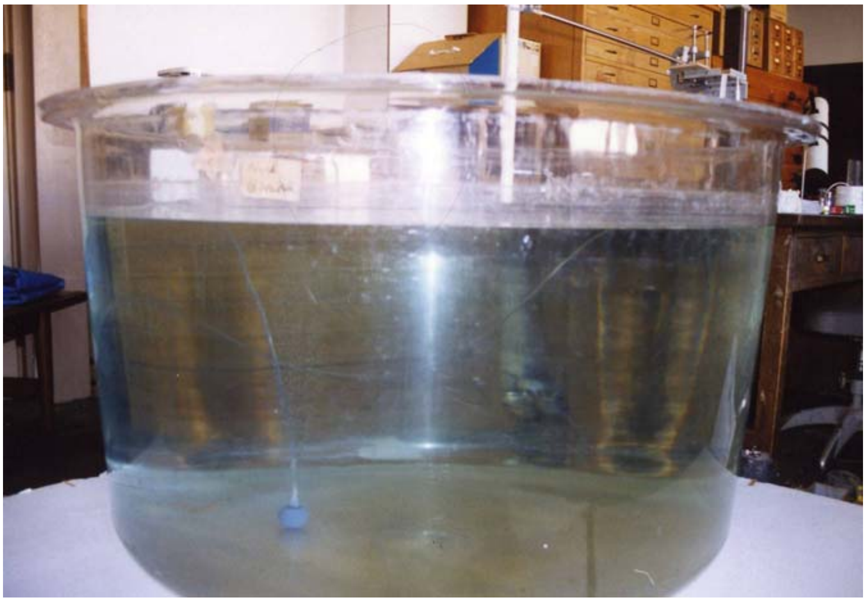


Fig. 1 Rearing tank and aerator

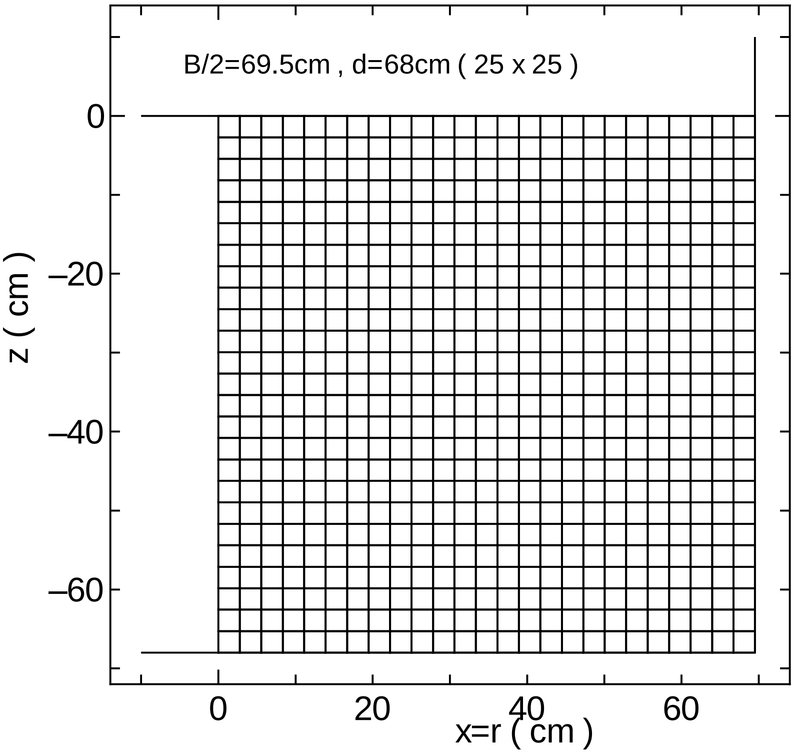


Fig. 2 Grid topology

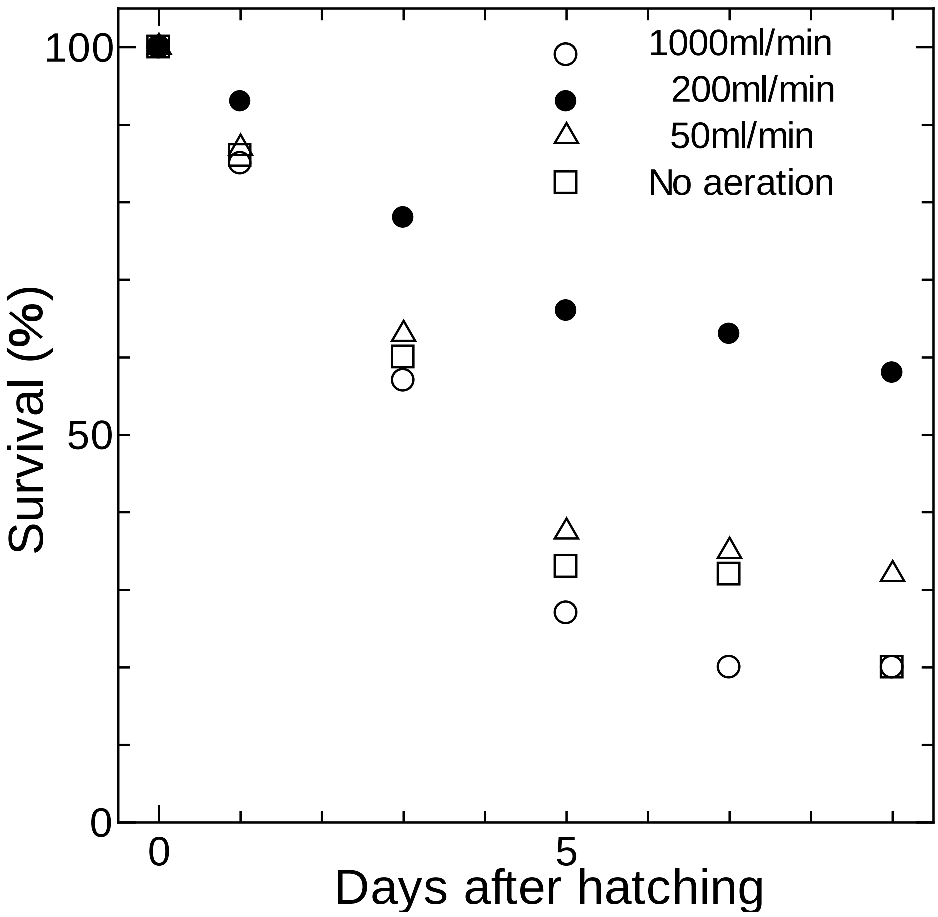


Fig. 3 Effect of aeration on the survival of *Epinephelus septemfasciatus* larvae.

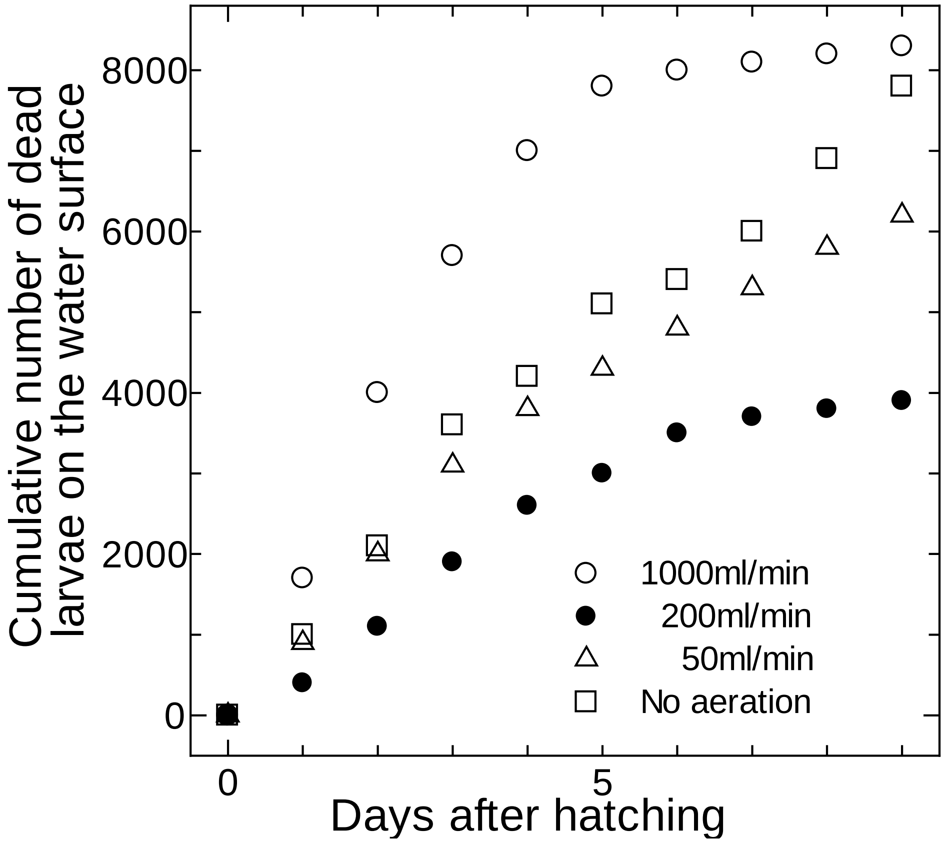
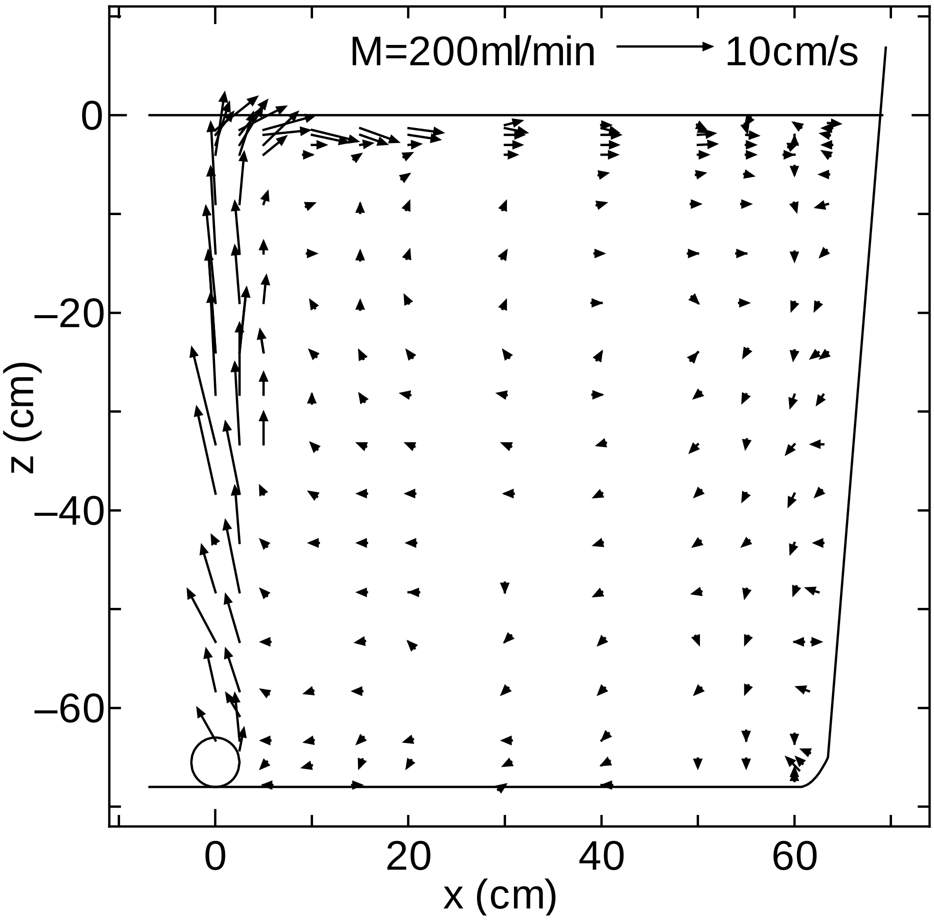
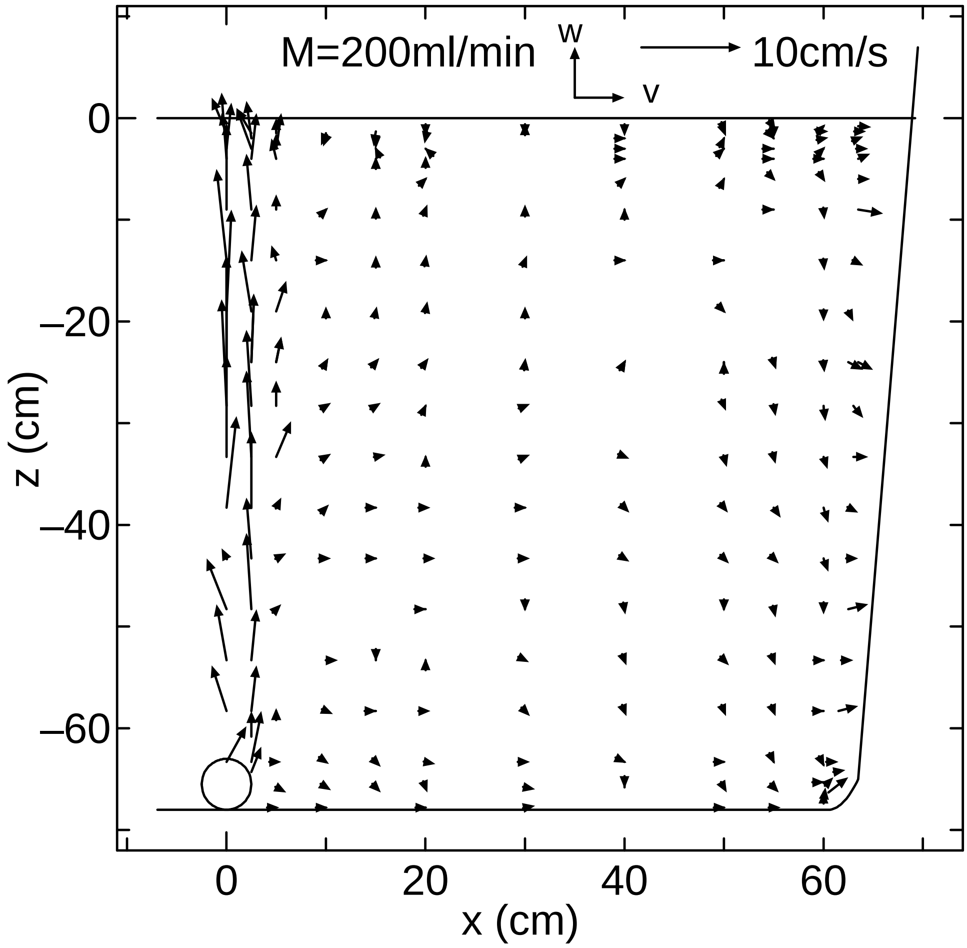


Fig. 4 Effect of the aeration rate on the floating death of *Epinephelus septemfasciatus* larvae.



(A) u-w distribution



(B) v-w distribution

Fig. 5 Experimental distribution of the stream velocity

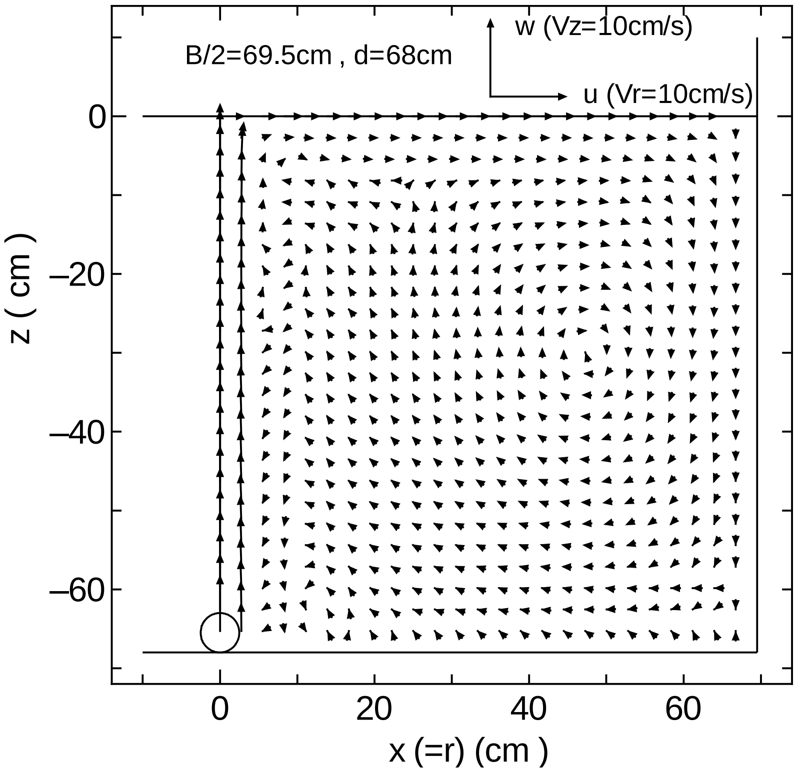
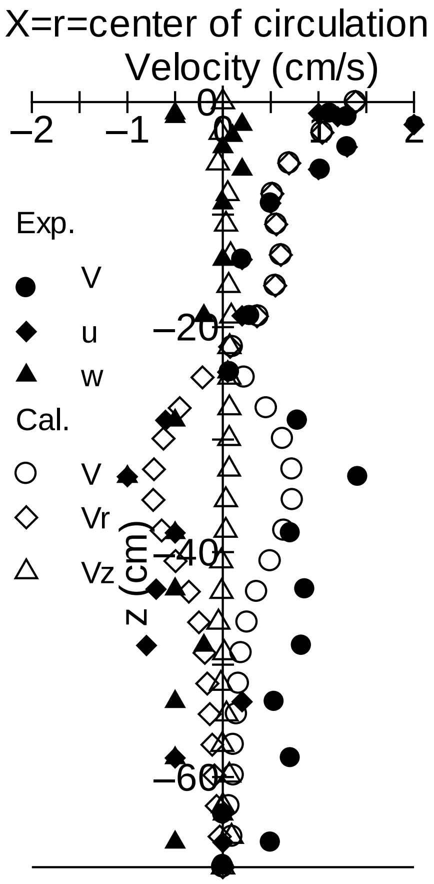
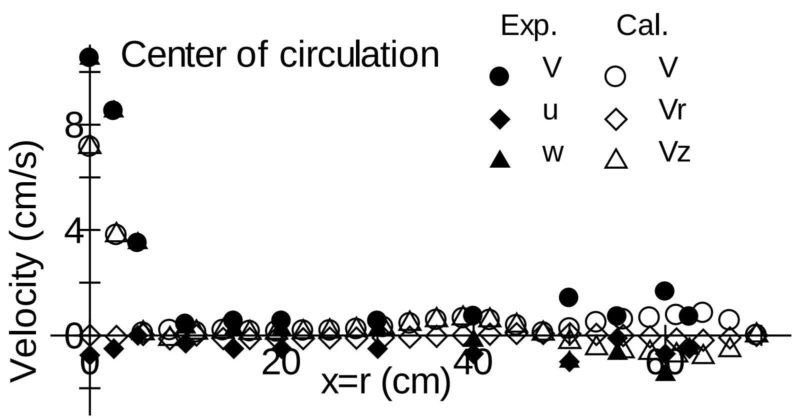


Fig. 6 Calculated distribution of the stream velocity



(A) Vertical velocity distribution



(B) Horizontal velocity distribution

Fig. 7 Comparison of the calculated and experimental velocity distributions on the vertical and horizontal lines through the center of vertical circulation in the rearing tank

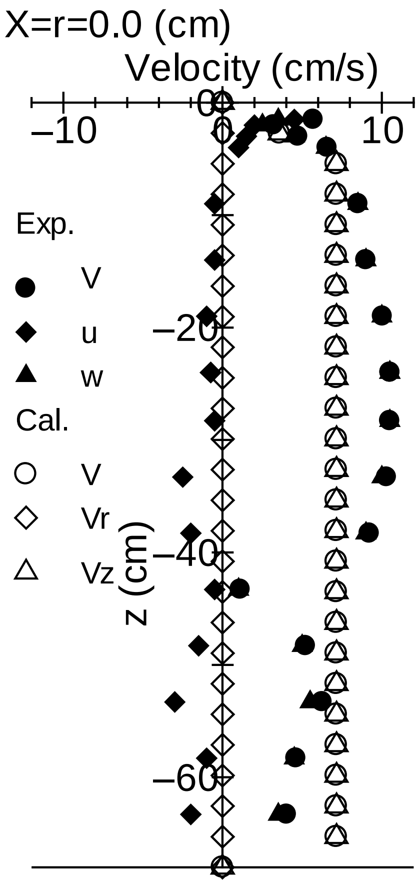
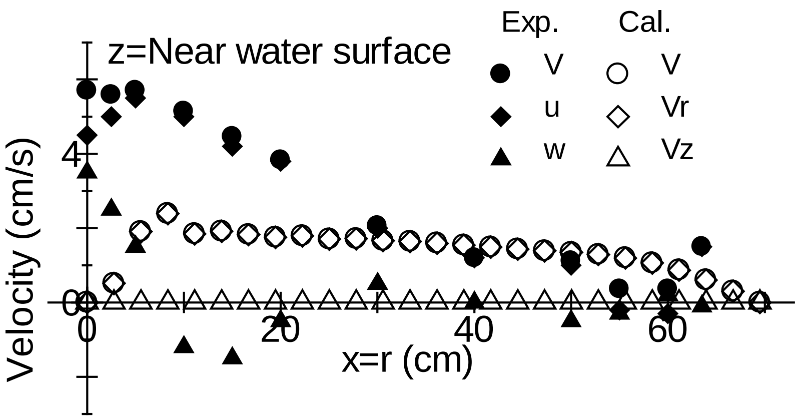
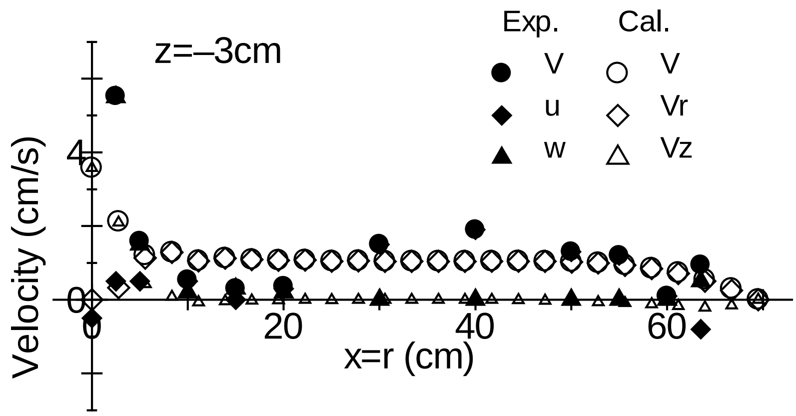


Fig. 8 Comparison of the calculated and experimental velocity distributions on the vertical center line of the rearing water tank


z=Near water surface
Exp.
Cal.
V
u
w
V
Vr
Vz
Velocity (cm/s)
4
0
0
20
40
60
x=r (cm)

(A) z = -1 cm



(B) z = -3 cm

Fig. 9 Comparison of the calculated and experimental velocity distributions near a free surface

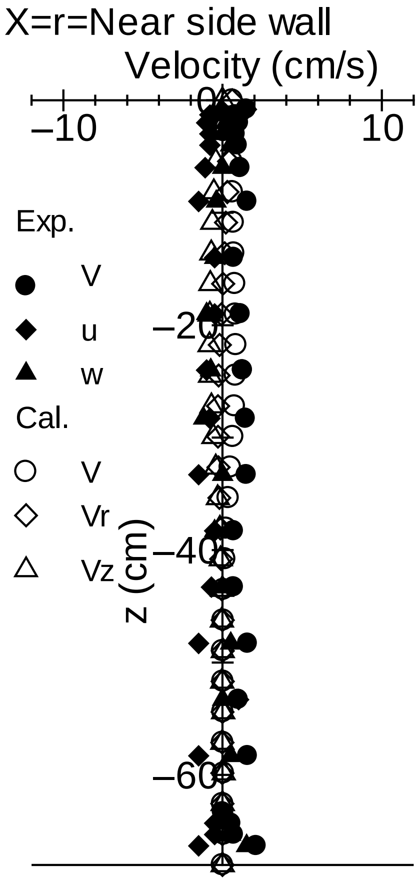
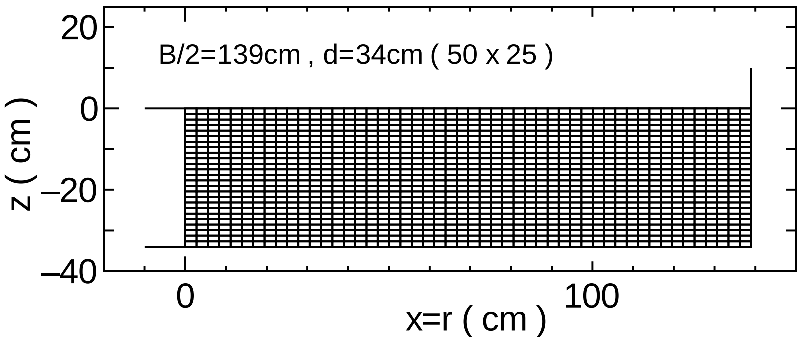
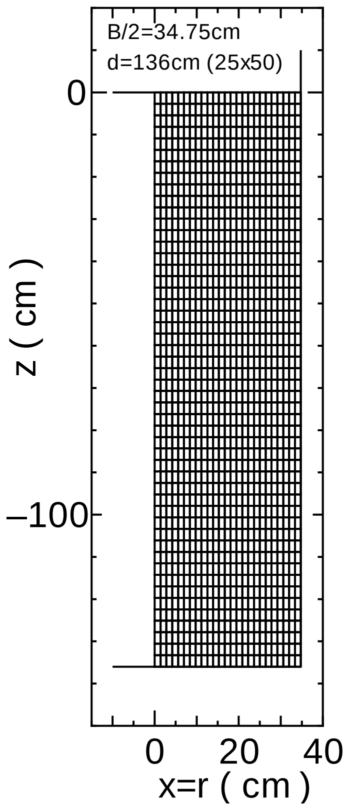


Fig. 10 Comparison of the calculated and experimental velocity distributions on the vertical line at distance of about 5 cm from the sidewall

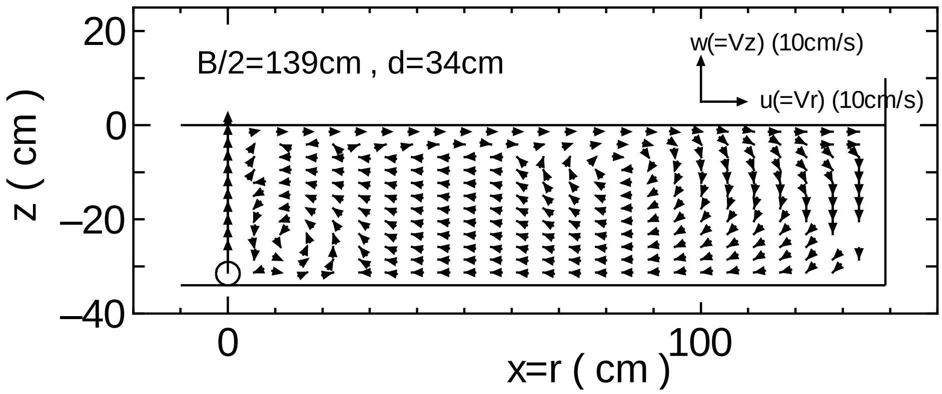


(A) B/d = 2.0/0.5

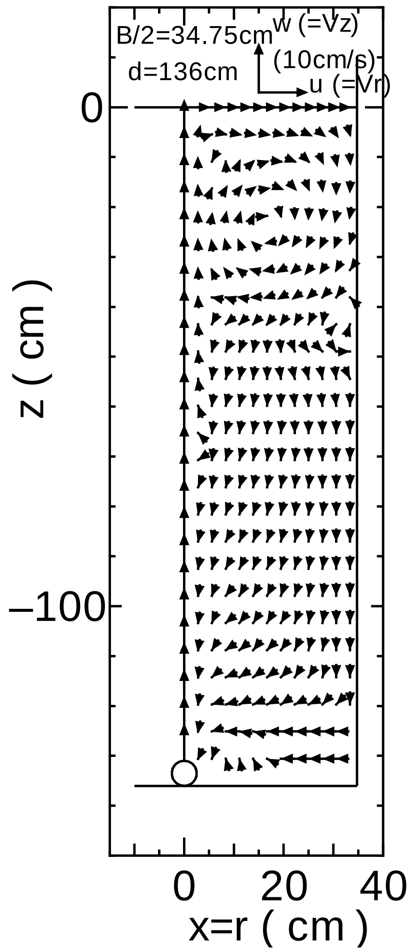


(B) B/d = 2.0/0.5

Fig. 11 Grid topology of two kinds of water tanks used for the flow estimation in the rearing of tank



(A) B/d = 2.0/0.5



(B) B/d = 0.5/2.0

Fig. 12 Calculated distribution of the stream velocity of two kinds of larvae water tanks

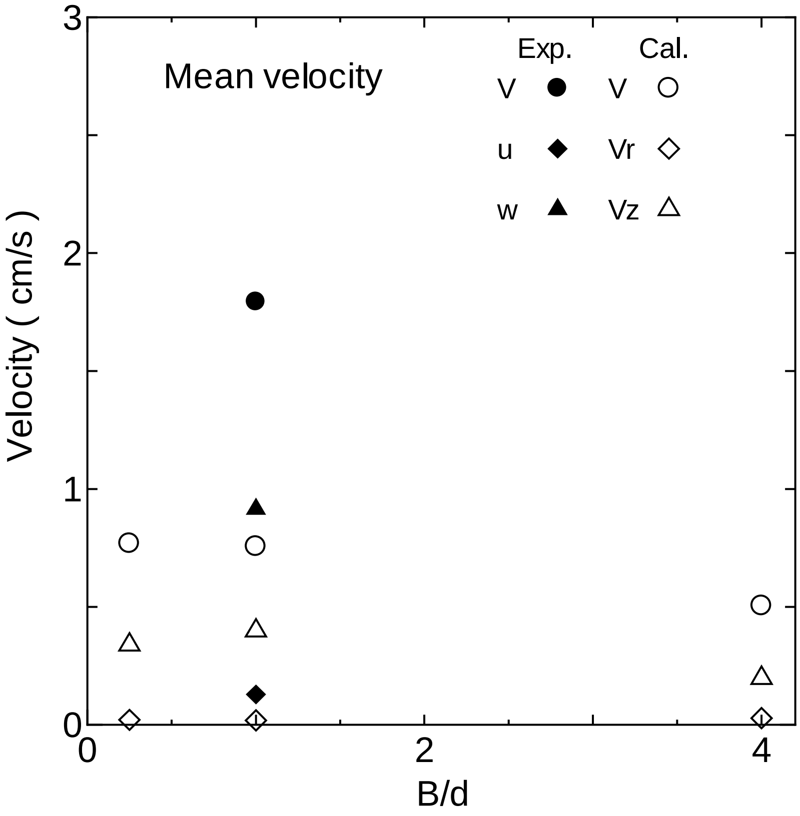


Fig. 13 Mean stream velocity in a larvae water tank

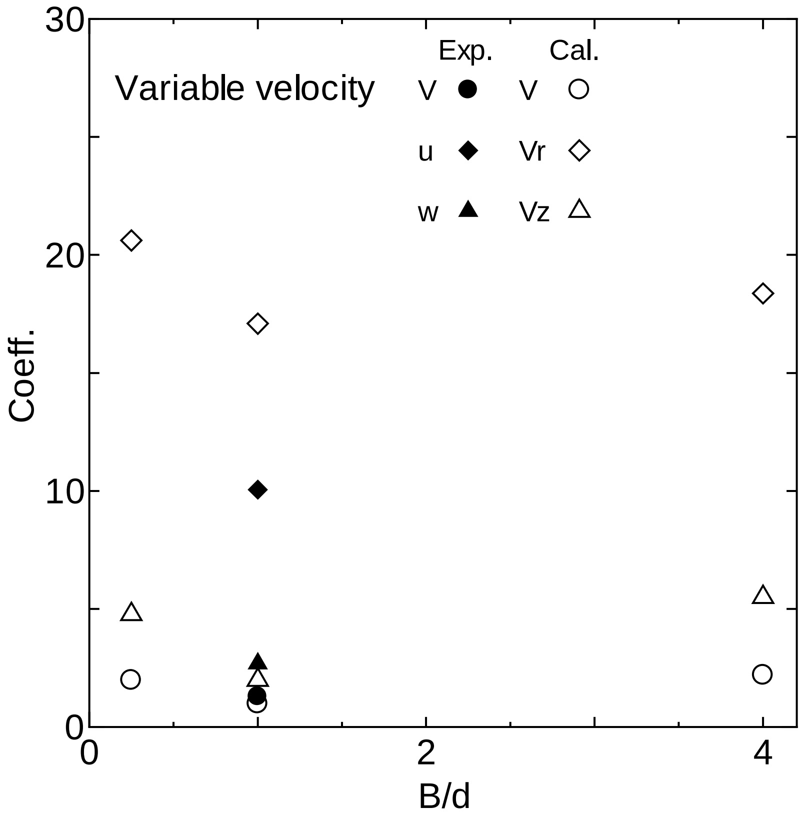


Fig. 14 Variable stream velocity in a larvae water tank