A INVESTIGATION OF THE DRAG COEFFICIENT IN A OPEN CHANNEL WITH GROUP OF COLUMNS

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ABSTRACT

The C_D of the single column and group of columns has been calculated to be approximately 1.0 using uniform flow velocity. It has been pointed out that the C_D of the group of columns is not constant due to the fact that the reproducibility drops when calculating the C_D of the group of columns constantly and due to the irregular flow past the group of columns. Therefore, it is necessary to make clear the C_D of individual columns constituting of group of columns or the entire group of columns, to reproduce the flow in the group of columns. In this study, numerical analyses and experiments were carried out to reproduce the flow in the group of columns and verify the C_D. As the results, when the C_D is 1.0, the experimental result could not be reproduced. Therefore, it was calculated using the C_D of the entire group of columns. However, result could not reproduce experimental results. By using C_D of the entire group of columns, reproduction rate improved by about 20 (%). In conclusion, since there was a place where the flow velocity remarkably decreased within the group of columns, the C_D was not constant. In addition, the ultimate purpose of this study is to reproduce a flow around the group of columns exactly and to carry out the fish habitat assessment in greater detail.

Keywords: group of columns, drag force, drag coefficient, reproduction of flow

1. INTRODUCTION

As shape coefficient of the column which is a drag coefficient; C_D and drag force F_{Dx} acting on an object of fluids is defined as follows.

$$F_{Dx} = \frac{1}{2}\rho C_D A U^2 \tag{1}$$

where, ρ is Water density (= 1,000 (kg/m^3)), C_D is shape drag coefficient of a column (drag coefficient), A is projected area of a column and U is characteristic flow velocity (m/s).

In addition, a drag coefficient; C_D of single column is arranged by relations with Reynolds number R_{ed} which assumed column diameter D characteristic length, and Reynolds number R_{ed} is defined as follows.

$$R_{eD} = \frac{UD}{\nu} \tag{2}$$

where, ν is dynamic viscosity (m^2/s).

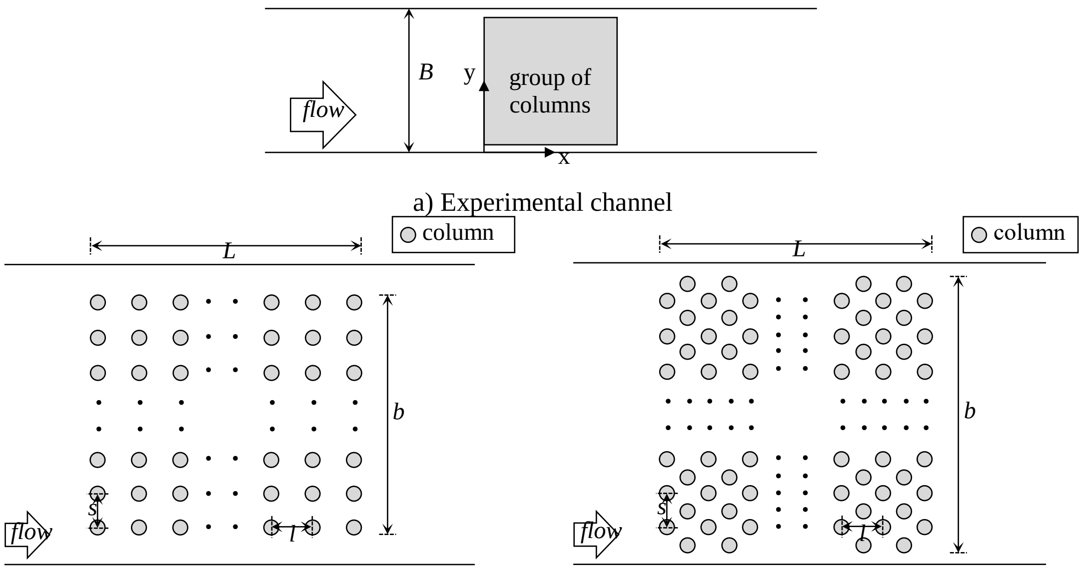
It is thought that the characteristic flow velocity U of Eq. (1) and Eq. (2) is the uniform flow. On the other hand, flow velocity distribution exists in a real fluid, and therefore, as for the drag coefficient C_D level of the single column, it is thought that it is different by a place, and it is thought that an again single column and the drag coefficient C_D of the group of columns are different. Columns are used as tree and simulation such as vegetation, spur dike well. Generally, the drag single column coefficient C_D is almost treated as 1.0, and the drag coefficient C_D of group of columns is often treated as a thing like the value of the single column, too. Fukuoka and Fujita counted a drag coefficient C_D group of columns of the staggered arrangement backward with 1.2 from the rough degree coefficient that we calculated from a base rough degree coefficient. As the results of experiment on group of columns as square placement, and having counted a drag coefficient C_D of the whole group of columns backward using inherent penetration flow velocity, Shimizu et al. Showed an approximately agreed thing to the drag coefficient C_D of equality flow velocity columns. In this way, the drag whole group of columns coefficient C_D almost fits a drag single column coefficient C_D, and it is shown to be almost a constant value. However, the possibility that it is shown that a drag coefficient C_D fluctuates with increase and decrease, the lower column of the column of neighboring two with a change of the Froude number Fr, the drag coefficient C_D of the non-submergence column that a drag coefficient C_D of group of columns grows big with the increase of the thick growth degree, and it is not with the constant value, drag coefficient C_D is suggested. In addition, it is pointed out that the reproduction precision of the flow declines when it uses a drag constant value coefficient C_D for numerical analysis. As the results of having calculated a drag coefficient C_D of group of columns as a constant value, rise of a river and pointed out that reproducibility fell when the space of the column was small. In addition, when Yokojima et al. Calculated a drag coefficient C_D as a constant value, it is guessed that a drag coefficient C_D is underestimated about the column located in the downstream region in the group of columns. Therefore, possibility of the improvement of the result is suggested by using an appropriate value for individual columns. As the results of Aoki et al. Changing the drag individual columns coefficient C_D which constituted group of columns, and having calculated it, we showed that the reproduction precision of the flow improved. However, it may be said that the appropriate value of the drag coefficient C_D of group of columns is not yet established. As for this, it is thought that the drag coefficient C_D is to change by how to get representative flow velocity U according to the ceremony of (1). In addition, the flow to be over a column line has a strong irregularity, and the possibility that what big resistance occurs is shown, and it is not with the constant value, drag coefficient C_D in the group of columns is guessed. It is thought that it is important to make the drag coefficient C_D of the individual column constituting the whole group of columns or a group of columns clear to reproduce a flow in the group of columns in greater detail.

Therefore, it is necessary to make clear the C_D of individual columns constituting of group of columns or the entire group of columns, to reproduce the flow in the group of columns. In this study, numerical analyses and experiments were carried out to reproduce the flow in the group of columns and verify the C_D. In addition, the ultimate purpose of this study is to reproduce a flow around the group of columns exactly and to carry out the fish habitat assessment in greater detail.

2. EXPERIMENTAL METHODS AND NUMERICAL ANALYSIS METHODS

2.1 Experiments

The experiments were carried out by using a small open channel in the laboratory of Toyo University. Figure 1 shows the open channel used for the experiments. Width size of open channel; B is 80(cm), total length of open channel is 1,000.8(cm). Material of the column is stainless whose diameter is 1.0(cm), and set up in the center of open channel. Table 1 shows the cases considered in the experiments.



b) Run1 (alignment arrangement)

c) Run2 (zigzag arrangement)

Figure 1. Plain view of open channel for the experiments.

Table 1. Cases considered in the experiments.

Experimental case	Quantity of flow Q(l/s)	Number of column T	Interval in x direction l(cm)	Interval in y direction s(cm)	Group of columns		
					Arrangement	Length L(cm)	Width b(cm)
Run1	16.0	361	4.0	4.0	alignment arrangement	73.0	73.0
Run2		721	4.0	4.0	zigzag arrangement	73.0	77.0

2.1.1 Measurement of drag force

Figure 2 shows the set up the multi-component load cell. The multi component load cell was used to measure the drag force acting on each column. Drag force F_{Dx} is defined Eq. (3).

$$F_{Dx} = \frac{1}{2}\rho \cdot C_D \cdot A \cdot U^2 = \frac{1}{2}\rho \cdot C_D \cdot d \cdot h \cdot U^2 \quad (3)$$

where, *d* is diameter of a column (m) and *h* is characteristic water depth (m).

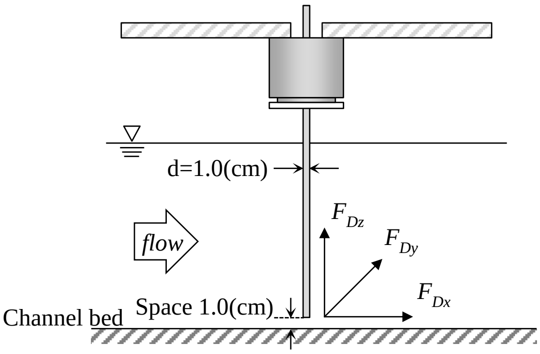


Figure 2. Set up the multi-component load cell for measuring the drag force.

2.1.2 Measurement of flow velocity and water depth

The flow velocity *u* of the x direction is more remarkable than the flow velocity *v* of the y direction. Therefore, the flow velocity measured u of x direction. The flow velocity in the group of columns is slow. Then, the measurement of the flow velocity used a propeller-type current meter (product made in KENEK, VOT2-100-10) which was available for a measurement of the slight flow velocity. Figure 3 shows the water depth direction the flow velocity distribution in the group of columns inside. The flow velocity *u* of the water depth direction was the almost same. The flow velocity was measured by one-point method, because to decide the measurement point of the characteristics flow velocity (*U*).

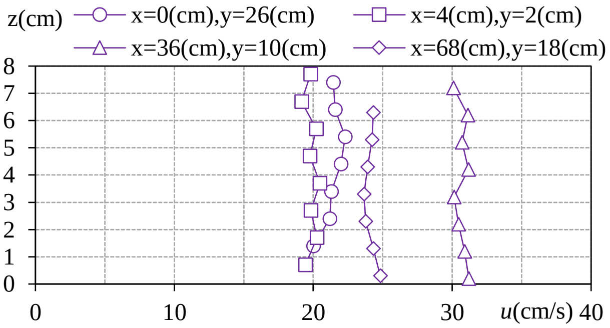


Figure 3. The water depth direction the flow velocity distribution in the group of columns inside.

In addition, assume sampling frequency of the flow velocity 20(Hz), and measure 512 data; and single; averaged it purely. Additionally, the water depth measured it using a point gauge (product made in KENEK, PH-102). Moreover, it is thought that whole group of columns or the representative flow velocity *U* when we calculate the drag coefficient C_D for individual columns constituting group of columns and the representative water depth h should use the value just before each column. Therefore, the flow velocity and the measurement of the water depth are the 1(cm) upper reaches of individual columns constituting the whole group of columns or the group of columns. This is the point that can come close in a column in a propeller current meter to the maximum.

2.2 Numerical analysis

Flow in an open channel with group of columns is computed using a two-dimensional shallow water equation and an equation of continuity. Dynamic equation in x and y direction, and equation of continuity is defined Eq. (4), (5) and (6).

<Dynamic equation in x direction>

$$\frac{\partial M}{\partial t}+\frac{\partial uM}{\partial x}+\frac{\partial vM}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{gn^2u\sqrt{u^2+v^2}}{h^{\frac{1}{3}}}+\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial M}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon\frac{\partial M}{\partial y}\right)-\frac{g}{K^2}M\sqrt{u^2+v^2} \quad (4)$$

<Dynamic equation in y direction>

$$\frac{\partial N}{\partial t}+\frac{\partial uN}{\partial x}+\frac{\partial vN}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{gn^2v\sqrt{u^2+v^2}}{h^{\frac{1}{3}}}+\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial N}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon\frac{\partial N}{\partial y}\right)-\frac{g}{K^2}N\sqrt{u^2+v^2} \quad (5)$$

<Equation of continuity>

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \quad (6)$$

Where, u is velocity in the x direction, v is velocity in the y direction, $M(=uh)$ is flux in the x direction, $N(=vh)$ is flux in the y direction, h is water depth, H is water level and ε is eddy viscosity. K in eq. (4) and (5) is the coefficient of permeation and is represented as follows.

$$K=\frac{1}{\sqrt{\frac{C_D\cdot a_W}{2g}}} \quad (7)$$

where, a_W is the projected area by group of columns in mass of water with unit volume and is shown as follows.

$$a_W=\frac{T\cdot A}{L\cdot b\cdot h} \quad (8)$$

where, T is total number of columns, L is interval in x direction of group of columns and b is interval in y direction of group of columns. Table 2 shows the cases considered in the numerical analyses.

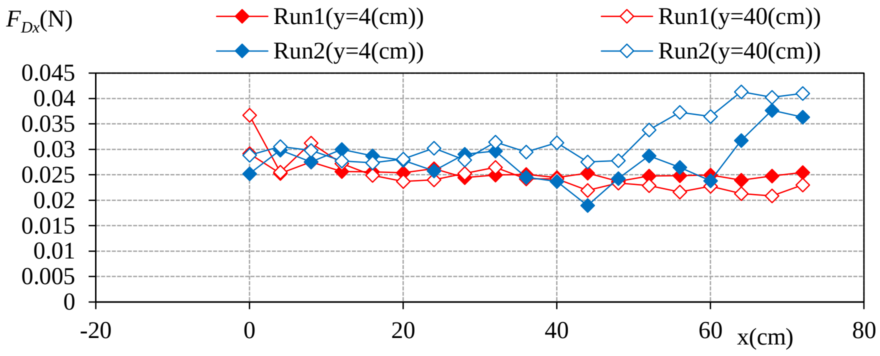
Table 2. Cases considered in the numerical analyses.

<table>
<tr><th rowspan="2">Numerical analyses case</th><th rowspan="2">Number of column T</th><th rowspan="2">Interval in x direction l(cm)</th><th rowspan="2">Interval in y direction s(cm)</th><th colspan="3">Group of columns</th><th rowspan="2">C_D</th><th rowspan="2">a_w</th></tr>
<tr><th>Arrangement</th><th>Length L(cm)</th><th>Width b(cm)</th></tr>
<tr><td>Run3-1</td><td rowspan="3">361</td><td rowspan="3">4.0</td><td rowspan="3">4.0</td><td rowspan="3">alignment arrangement</td><td rowspan="3">73.0</td><td rowspan="3">73.0</td><td>1.0</td><td rowspan="2">whole group of columns</td></tr>
<tr><td>Run3-2</td><td rowspan="2">each value</td></tr>
<tr><td>Run3-3</td><td>single column</td></tr>
<tr><td>Run4-1</td><td rowspan="3">721</td><td rowspan="3">4.0</td><td rowspan="3">4.0</td><td rowspan="3">alignment arrangement</td><td rowspan="3">73.0</td><td rowspan="3">77.0</td><td>1.0</td><td rowspan="2">whole group of columns</td></tr>
<tr><td>Run4-2</td><td rowspan="2">each value</td></tr>
<tr><td>Run4-3</td><td>single column</td></tr>
</table>

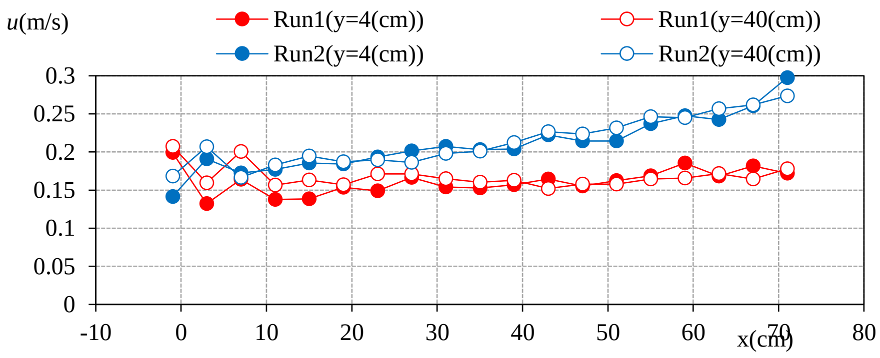
3. Results

3.1 Experiments

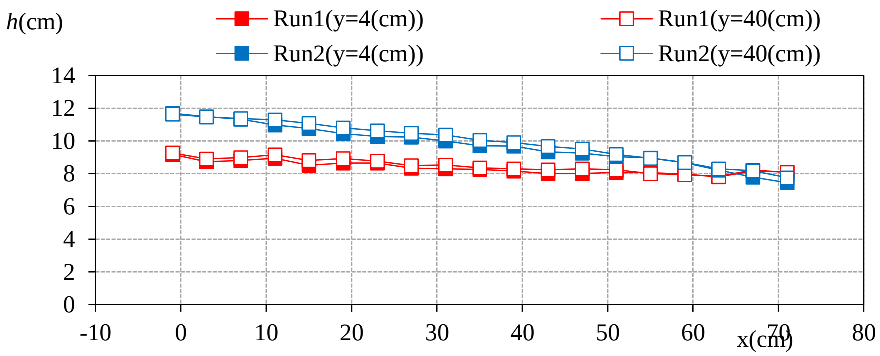
Figure 4 shows the flow velocity u, water depth h, and drag force F_{Dx} in Run1 and Run2. In addition, Figure 4 d) is drag coefficient C_D using Eq. (3). In Run1(aligned arrangement), the drag coefficient C_D of the second column was increasing. This is because the drag force F_{Dx} of the second column from the upstream has been reduced. Because l/d is 4, wake effects are possible.



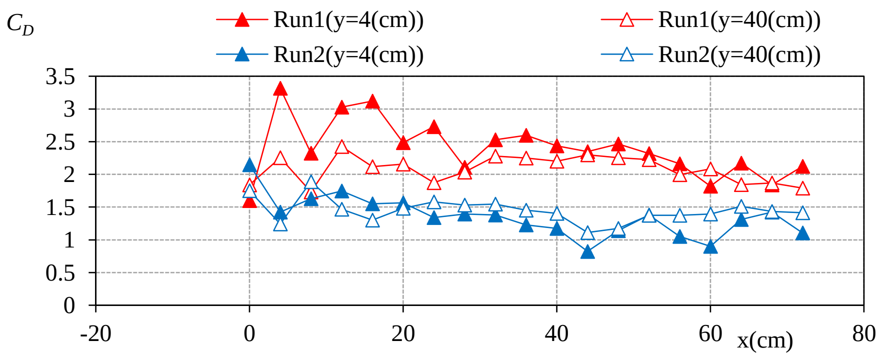
a) Drag force



b) Flow velocity



c) Water depth

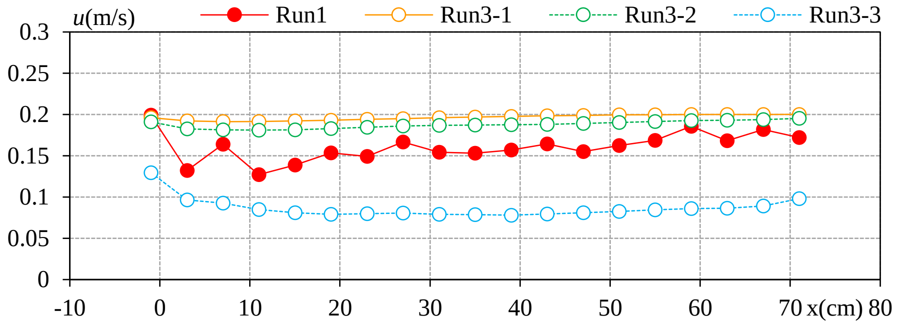


d) Drag coefficient

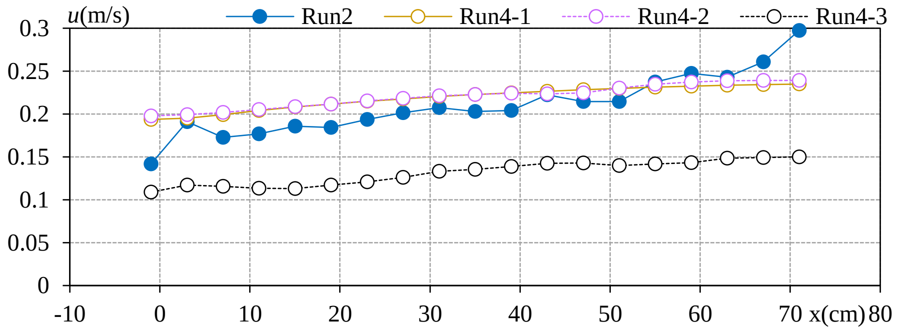
Figure 4. The results of experiments.

3.2 Numerical analyses

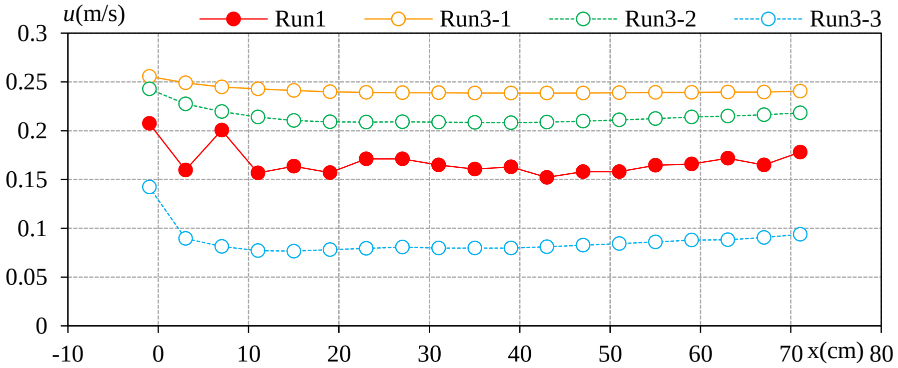
Figure 5 shows the longitudinal change in the velocity *u* at the right bank of the channel (y=4(cm)) and at the center of the channel (y=40(cm)). In Run3-1, the flow velocity u tends to decrease downstream. The remarkable flow velocity reduction tendency, such as Run1, could not be reproduced. In Run4-1, the tendency of the flow velocity u to increase downstream could be reproduced. However, the recall was low especially at the center of the channel (y=40(cm)). In Run3-2, Run4-2 and Run3-3, Run4-3, the calculation was performed by applying the drag coefficient C_D of each column constituting the group of columns. Run3-2 and Run4-2 showed the same tendency as the calculation results (Run3-1 and Run4-1) that the drag coefficient C_D was fixed. In Run3-3, the flow velocity *u* became slower overall, but the tendency of the flow velocity *u* could be reproduced. In Run4-3, the flow velocity *u* also became slower overall, but the tendency of the flow velocity *u* could be reproduced. Therefore, the tendency of the drag coefficient C_D obtained in the experiment is considered to be appropriate. In addition, it is considered that the calculation result is affected by the column installation area *A*. This is because the result of the flow velocity *u* differs between Run3-2, Run4-2 and Run3-3, Run4-3. It was possible to reproduce the tendency of flow velocity *u* that the column installation area A was the area of one column. Therefore, it is considered appropriate to handle this installation area. In Run3-3 and Run4-3, the flow velocity u became slower overall. This is probably due to the drag coefficient C_D.



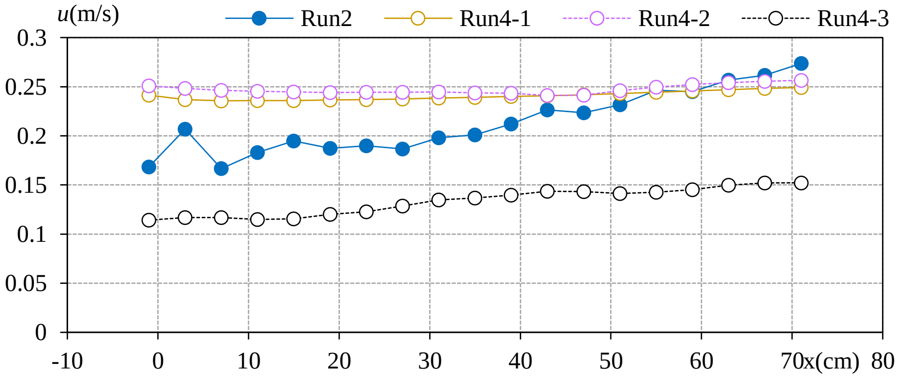
a) Alignment arrangement, y=4(cm)



b) Zigzag arrangement, y=4(cm)



c) Alignment arrangement, y=40(cm)



d) Zigzag arrangement, y=40(cm)
Figure 5. The results of numerical analyses.

4. CONCLUSIONS

In the experiment, drag coefficient C_D increased in Run1 (aligned sequence). This is because the second column (y=4(cm)) from the upstream of the group of columns was affected by the flow velocity reduction. In Run2 (zigzag arrangement), the flow velocity u tended to increase downstream. For these reasons, it was found that the drag coefficients C_D of the individual columns constituting the group of columns were different values.

As the results of calculation with the drag coefficient C_D as a constant value, the flow velocity u of Run3-1 decreased toward the downstream, and the remarkable reduction of the flow velocity observed in the experimental results could not be reproduced. In Run4-1, the increasing tendency of the flow velocity u could be reproduced, but the reproducibility was low in the upstream part of the group of columns.

The calculation was performed by applying the drag coefficient C_D of each column constituting the group of columns. As a result, it was found that the calculation results varied depending on the installation area A of the column.

In Run3-3 and Run4-3, the flow velocity u became slower overall, but the tendency of the flow velocity u could be reproduced. Therefore, the tendency of the drag coefficient C_D is considered appropriate.

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