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EXPERIMENTAL INVESTIGATION OF THE FLOWFIELD OF DUCT FLOW WITH AN INCLINED JET INJECTION
— DIFFERENCE BETWEEN FLOWFIELDS WITH AND WITHOUT A GUIDE VANE —

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ABSTRACT

An experimental study is carried out in order to investigate the possibility of deflecting inclined jet flow by means of a guide vane. The present study provides basic knowledge on designing the tunnel ventilation facility. A 7,700-mm-long main duct with a 230 mm x 230 mm square cross section is constructed. The main duct has an injection nozzle with an opening of 92 mm x 20 mm. The nozzle is installed at an angle of 30 degrees 1,780 mm downstream from the beginning of the main duct. Velocity distributions were measured both with and without the guide vane. The velocity distribution without a guide vane revealed a stronger downwash, whereas that with guide vanes showed weaker downwash.

INTRODUCTION

In longitudinally ventilated tunnels, which have recently become common in Japan, various jet apparatuses are introduced in order to drive the ventilation flow. Some of these apparatuses use an inclined jet injection of air into the traffic room, especially tunnels that are constructed using the open cut method. In this ventilation system, the air flow can disturb the traffic if the jet runs straight downward, and the velocity distribution in the region of turbulent mixing produced by the injection must be examined carefully. Although studies on the flowfieled having a jet injection parallel to the tunnel axis have been published(1)(2)(3), few studies have examined the inclined jet. The present authors have previously investigated experimentally the flow behavior in the mixing region after jet injection at an inclination angle of 30 degrees.(4) This investigation revealed that the flow was strongly dependent on the shape of the nozzle outlet. The flow was bent soon after the injection and traveled along the ceiling surface when injected by a full span nozzle, whereas the jet from a nozzle with a 40% span width maintained its direction and continued to flow downward.

In the present study, the authors apply various guide vanes in an attempt to prevent the downward flow from the 40% nozzle. In addition, the possibility of practical application is discussed. Two types of vanes, closed type and open type, were prepared for the present study. The closed type is designed to ensure performance, whereas the open type is designed as a more practical guide vane. The experimental results are discussed with respect to application in practical tunnels that require safer traffic conditions.

NOMENCLATURE

D : Hydraulic diameter (= 230 mm)
V_1 : Mean velocity in the upstream cross section
V_2 : Mean velocity in the downstream cross section
V_j : Jet velocity
x, y, z : Coordinates
ψ : Velocity ratio ($= V_j / V_2$)
Re : Reynolds number ($=V_2 D / \nu$)

EXPERIMENTAL APPARATUS

Figure1 shows the side view of the duct used in the present experiment. The main duct has a square cross section of 230 mm x 230 mm (for a square, the side length is equal to hydraulic diameter, which is taken as the reference length D). The total length of the experimental setup is 8,800 mm. The straight main duct is constructed of plexi-glass and has a length of 7,700 mm. The exhaust fan at the end of the duct is driven by an inverter in order to maintain the main flow in the range from 4 to 10 m/s. The corresponding Reynolds numbers range from 6.1×10^4 to 1.5×10^5. A 30-degree inclined air jet is blown into the main duct 1,780 mm downstream from the beginning of the main duct. This angle is common in practical tunnels. The flow velocity of the jet can be set arbitrarily through an orifice measurement. The flow rate of the main duct is set to a prescribed value which is calculated in terms of the pressure difference between the outside air and the beginning of the main duct. The flow rate is calibrated as the integration of the velocity distribution. The injection nozzle has an opening of 92 mm x 20 mm, which corresponds to 40% of the span of the ceiling. The coordinate system of the flowfield is defined in Fig. 2.

GUIDE VANES

closed type

The closed type guide vane used in the present experiment is illustrated in Fig. 3. The outlet cross section is 92 mm x 20 mm and the length of the plate parallel to the ceiling is selected as either 25 mm or 10 mm. The former is selected when safety is a concern, in order to assure that the flow attaches to the ceiling, whereas the latter is selected in order to minimize pressure loss.

open type

The closed type guide vane provides reliable flow deflection; however, a more conventional alternative is the open type, shown in Fig. 4, in which the oblique plate is removed. The open type guide vane produces a weaker flow deflection than the closed type. Both types of vane are tested for a length of either 10 mm or 25 mm.

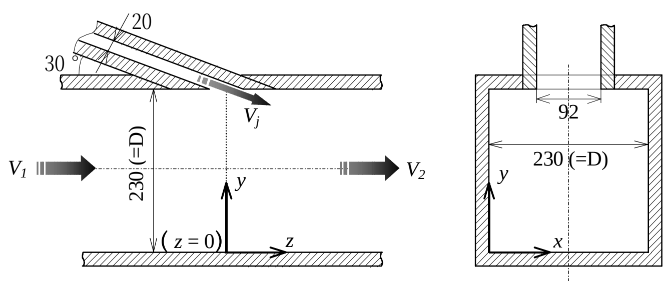

Fig. 2 Coordinate system (units : mm)

EXPERIMENT

EXPERIMENTAL RESULTS

The airflow velocity is measured at downstream cross sections at the following distances from the outlet. z/D=0.5, 1, 2, 3, 5, 10, 15, 20. The Pitot tube is traversed in the y-direction at the following positions: x/D=0.1, 0.3 and 0.5. In the region of reverse flow, the Pitot tube is rotated to the opposite direction, which results in a dislocation of the measuring point that is equal to twice the length of the neck of the tube (tube neck length: 40 mm, total dislocation: 80 mm)

Actual values of the flow velocity in the traffic room range between 2 and 8 m/s, while the jet speed ranges from 10 to 30 m/s. In order to simulate closely the most frequent situation of ventilation operation, the velocity ratio $\psi=V_2/V_j$ is confined to 0.2 in the present study. V_j is a constant 30 m/s.

Figures 5 through 14 are the velocity distributions in z-direction at various locations for ducts with and without guide vanes. The measured velocities are normalized using the mean downstream velocity V_2.

In the duct without guide vane (Figs. 5 and 6), the jet proceeds downward, but the maximum velocity gradually decreases with cross section toward downstream. The safety criteria for traffic is set to 18 m/s (V/V_2=3), which is the average of V_j and V_2, in the region below 70% of the duct height (=D). In this case, the jet is assumed to affect the traffic, because V/V_2 becomes 3.03 at y/D=0.63 and z/D=2.

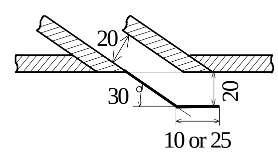

Fig. 3 Guide vane (closed type)(units : mm)

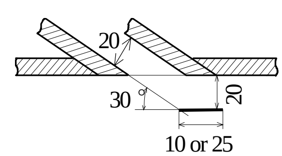

Fig. 4 Guide vane (open type)(units : mm)

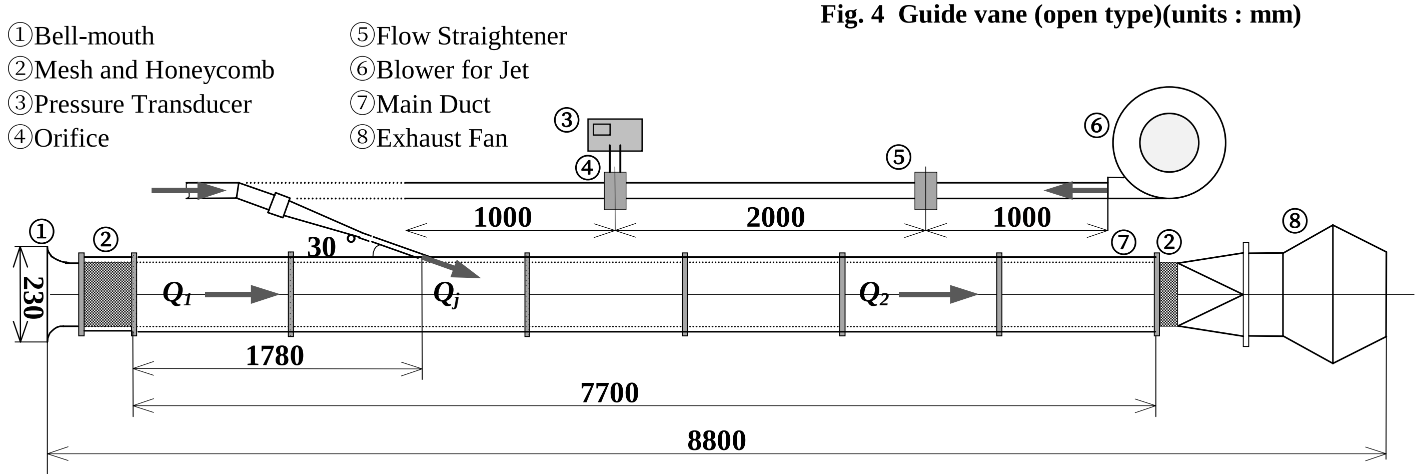

Fig. 1 Experimental apparatus (units : mm)

The point of maximum velocity moves downward as it travels downstream, but the velocity ratio remains below 3. In cross sections *z/D*=10, 15 and 20, the velocity profile recovers toward equilibrium. The recovery process is quicker in this duct than in the ducts with a guide vane. The jet is confined to a limited area and spreads little. Reverse flow regions are observed at the ceiling in the *z/D*=0.5 cross section and at the floor in the *z/D*=3 cross section.

When a guide vane of the closed type with a 10 mm plate is attached to the jet inlet, the jet is deflected dramatically, as is shown in Figs. 7 and 8. The high-speed region remains near the ceiling, assuring traffic safety. The most critical value is V/V_2=2.96 at *y/D*=0.85 in the cross section of *z/D*=3. As in the former case, the jet remains rather confined to a limited area. The velocity profiles at *z/D*=10 and 15 remain unsymmetrical.

When a 25-mm closed type guide vane (Figs. 9 and 10) is attached to the jet inlet, the mixing process is similar to that of the 10-mm vane; however, the attachment to the ceiling appears to be much stronger, revealing that the jet does not affect the traffic. The jet spreads in the horizontal direction when the 25-mm closed type guide vane is attached. The normalized velocity is observed to exceed 5 in cross sections *z/D*=0.5 and 1, which means that the actual velocity is partially larger than the mean injection velocity. The authors believe this phenomenon to be attributable to non-uniformity of the velocity distribution; however, the detailed flowfield remains unknown. The reverse flow region is not observed.

The open type vane, in which the inclined plate is removed, has different deflection characteristics. For the 10-mm open type vane (Figs. 11 and 12), the peak velocity point is observable until *y/D*=0.55 at *z/D*=10, which means that the vane works, although the deflection performance is not satisfactory. The maximum velocity ratio becomes 3.08 at a height of *y/D*=0.74 at *z/D*=2, which just clears the criteria for safety.

In contrast, the 25-mm horizontal plate, does not allow the jet to proceed downward (Figs. 13 and 14), the velocity distribution is similar to that of the 25-mm closed type guide vane. The jet is attached at the ceiling, and safety is assured. In cross section *z/D*=0.5, the maximum velocity exceeds 5. Notably, a rather large reverse flow region is observed in cross section *z/D*=10. The authors have no explanation for this phenomenon.

The peak velocity points are plotted in Fig. 15. Both the open type and closed type vanes with the 25-mm plate show perfect attachment of the jet to the ceiling, which results in a velocity profile that does not recover even 20*D* downstream. For the 10-mm open type vane, the deflection is marginal, whereas the 10-mm closed type vane bends the jet sufficiently.

CONCLUSION

The authors conducted an experimental study on the velocity distribution resulting from the injection of an inclined jet into the main flow in a square duct. The effect of the guide vane on the flowfield was investigated, and the following conclusions were reached**:**

(1) The closed type guide vanes caused a clearly observable deflection along the ceiling, regardless of the length of the horizontal plate.

(2) The open type vanes induced a weaker deflection. The 10-mm plate of the open type vane could not bend the jet adequately. The 25-mm plate produced a stronger deflection that was comparable to that produced by the 25-mm plate of the closed type guide vane.

(3) When the flow was strongly deflected by the 25-mm vanes (both closed and open types), the velocity distribution did not recover, even 20*D* downstream.

The present study confirmed that an appropriate guide vane can deflect the inclined jet flow, so that the high-speed flow does not disturb the traffic. The closed type vane had stable performance, whereas the open type appears to be more promising for practical application. However more detailed study is required in order to properly design the actual vanes. The results of the present study are of limited quantitative value because the Reynolds number in the experiment was one and a half order of magnitude lower than that of the actual tunnel.

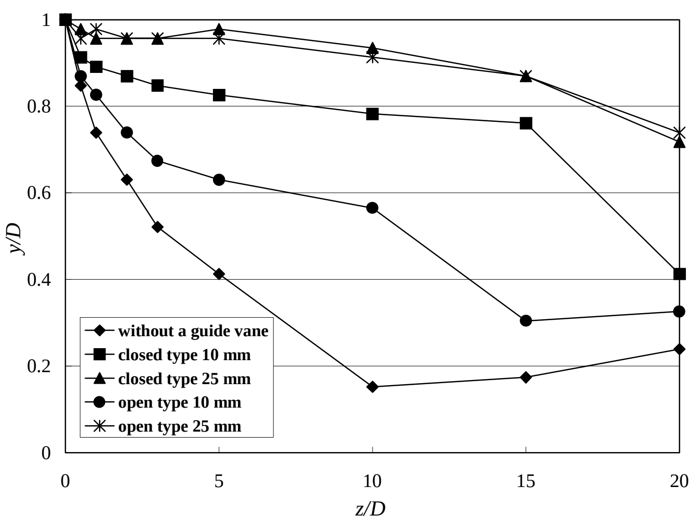

Fig. 15 Trajectory of the maximum velocity distribution points

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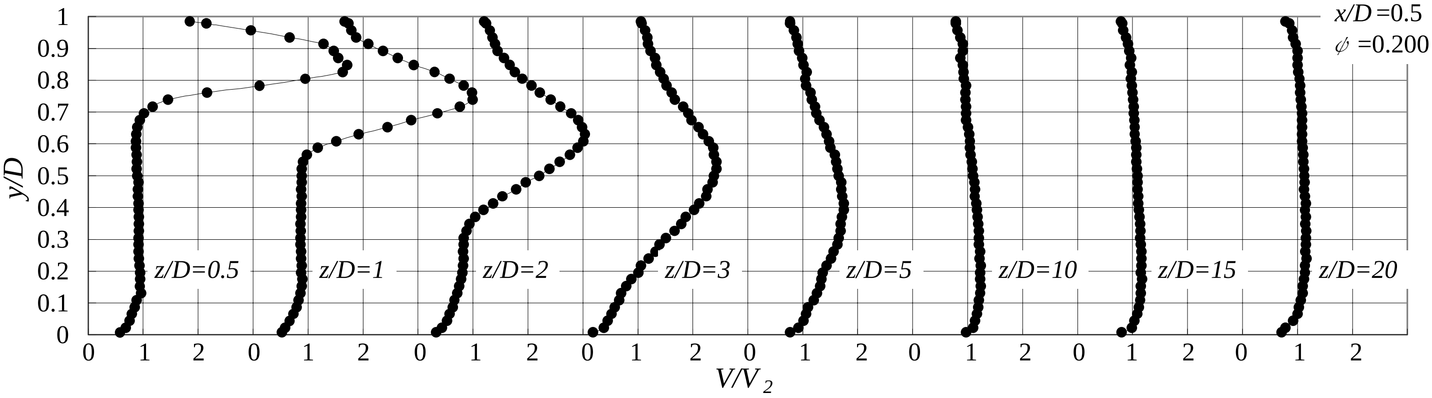

Fig.5 Velocity distribution in longitudinal section without a guide vane

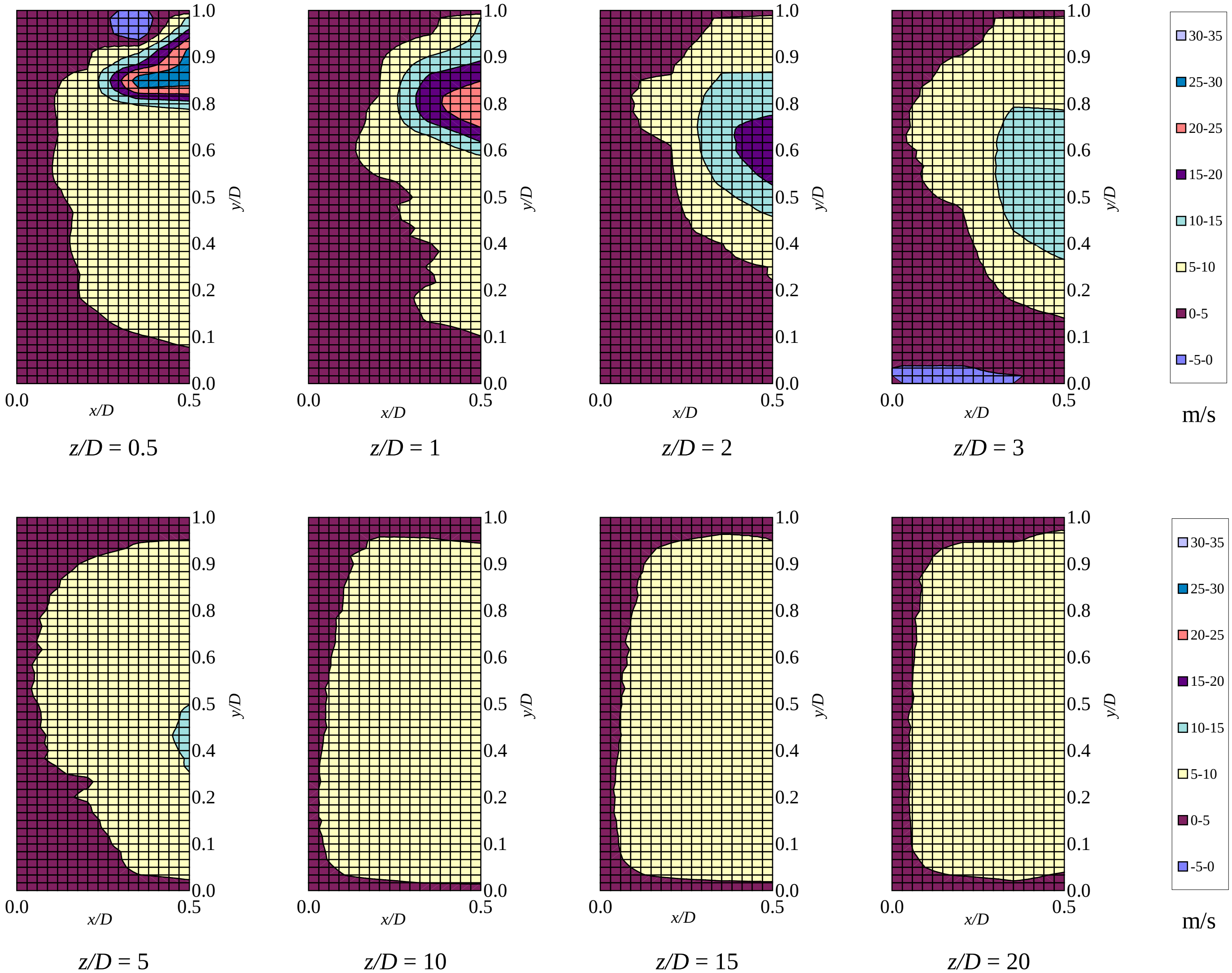

Fig.6 Velocity distribution in cross section without a guide vane

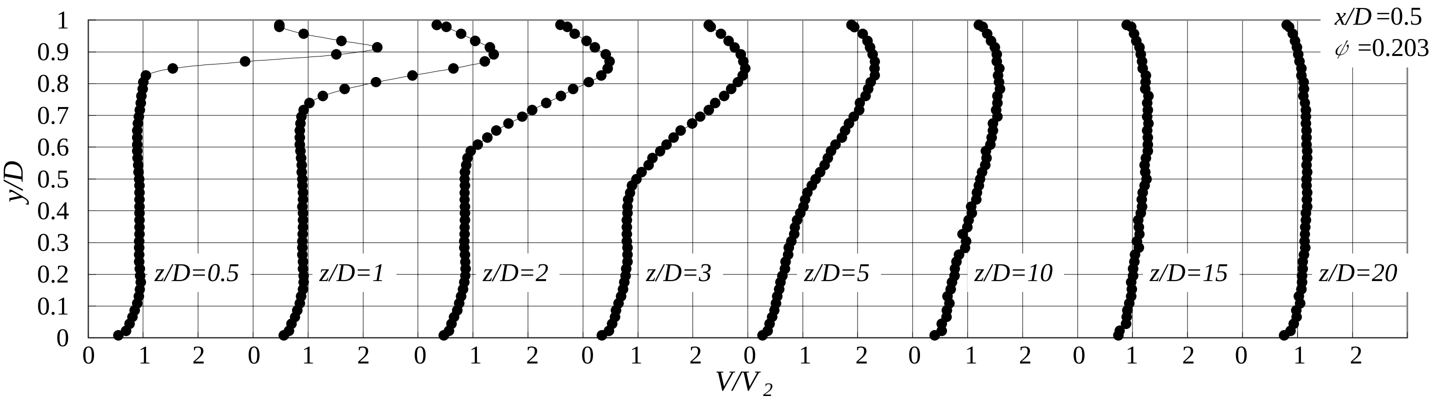

Fig.7 Velocity distribution in longitudinal section with guide vane (closed type 10 mm)

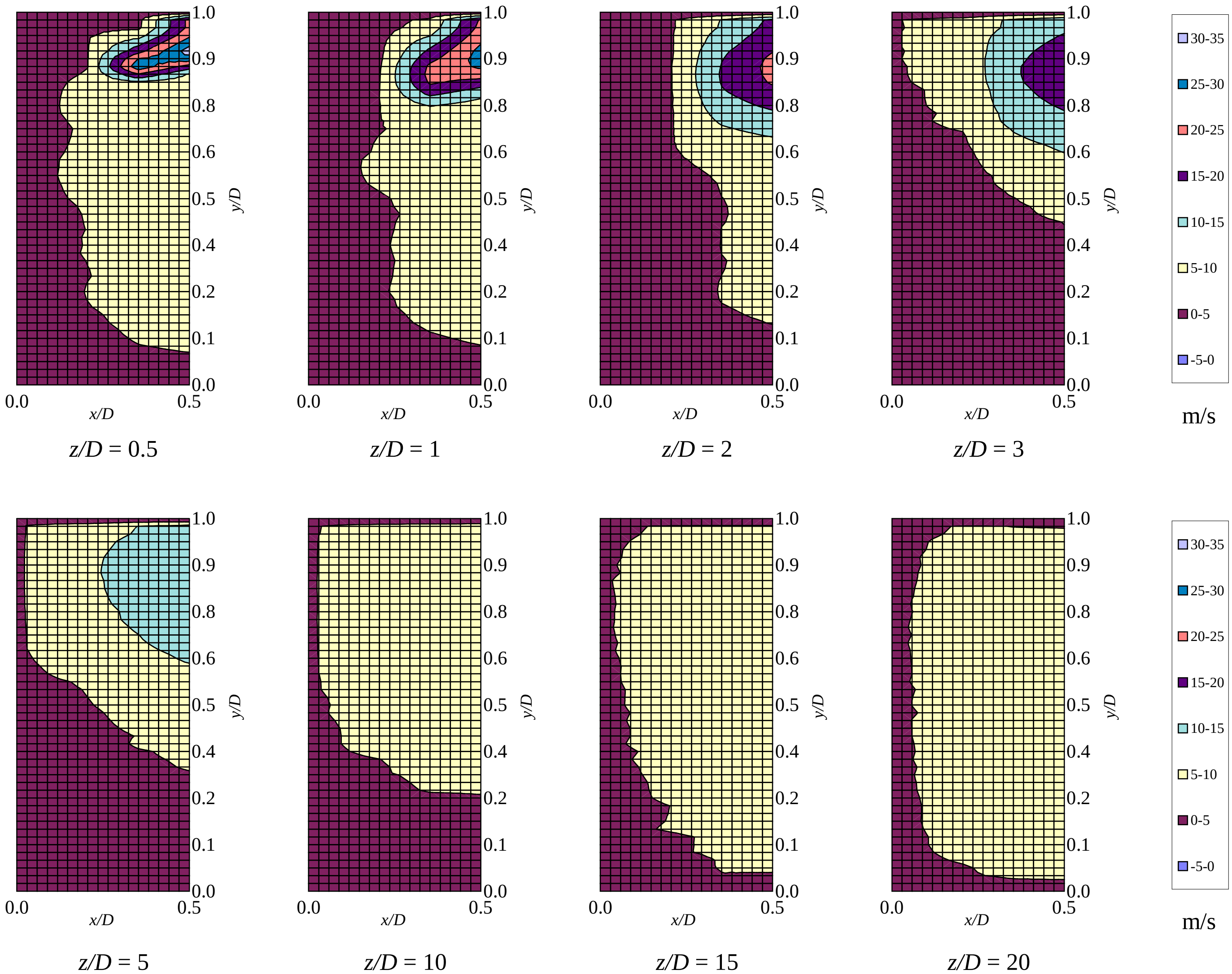

Fig.8 Velocity distribution in cross section with guide vane (closed type 10 mm)

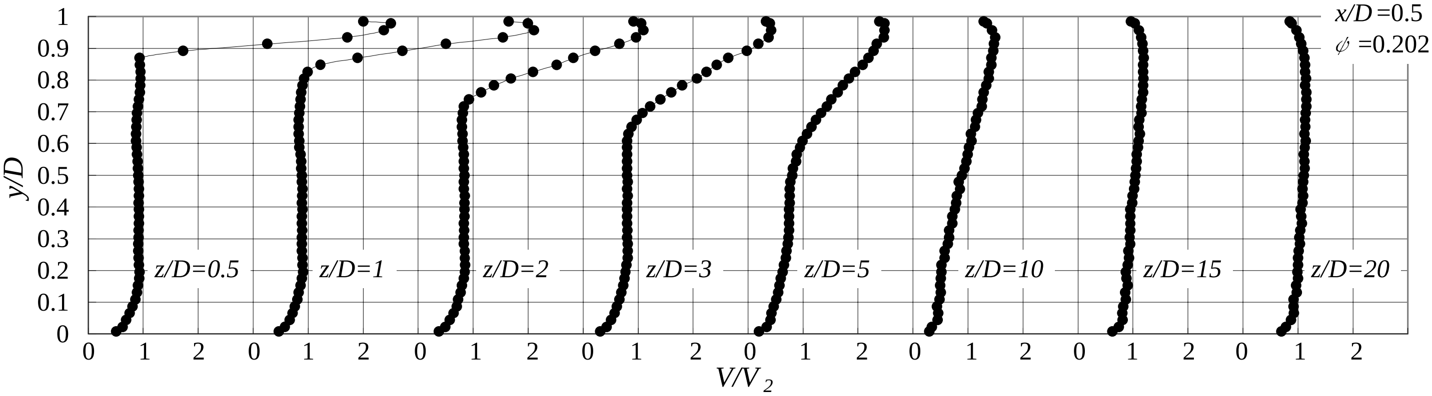

Fig.9 Velocity distribution in longitudinal section with guide vane (closed type 25 mm)

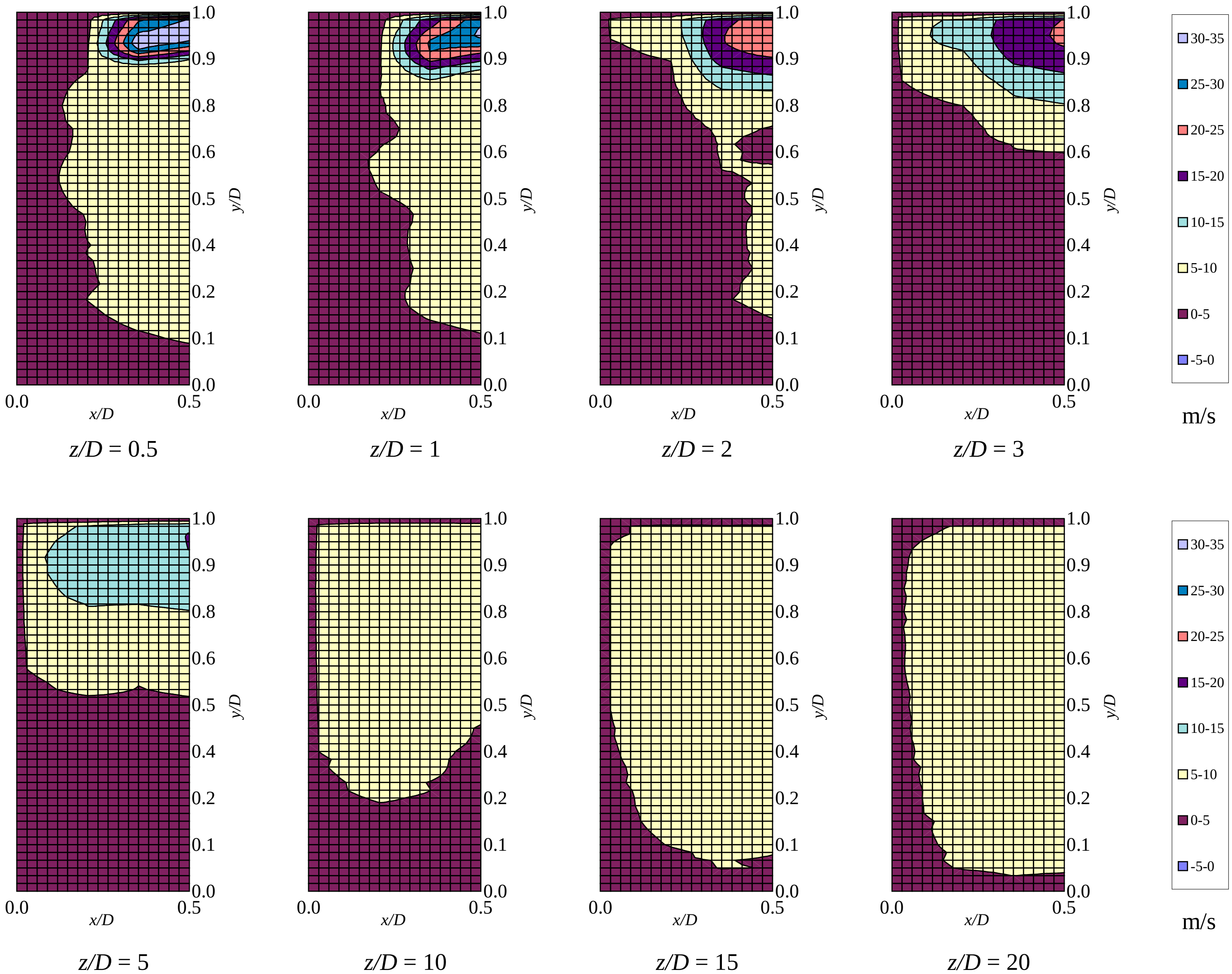

Fig.10 Velocity distribution in cross section with guide vane (closed type 25 mm)

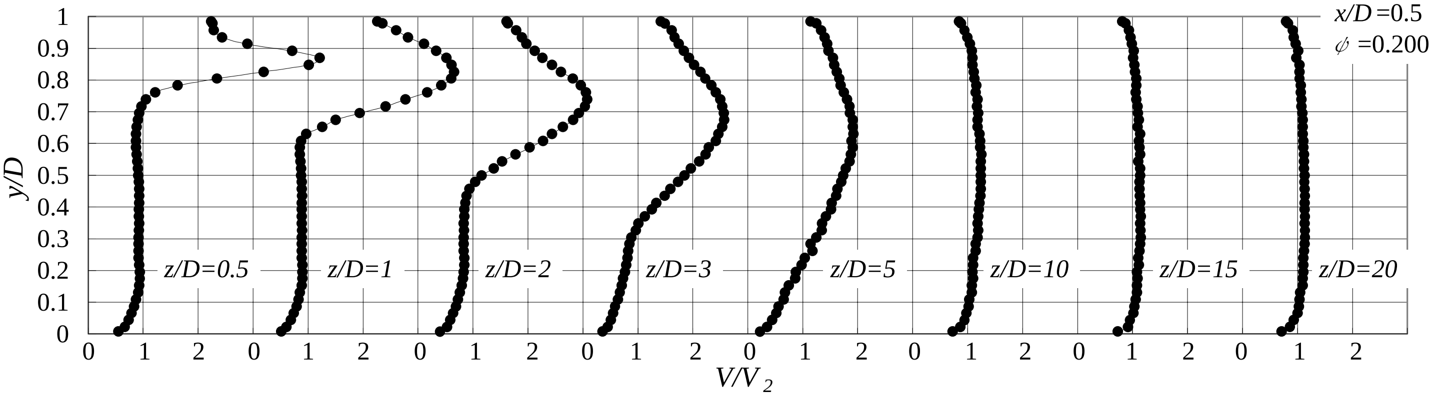

Fig.11 Velocity distribution in longitudinal section with guide vane (open type 10 mm)

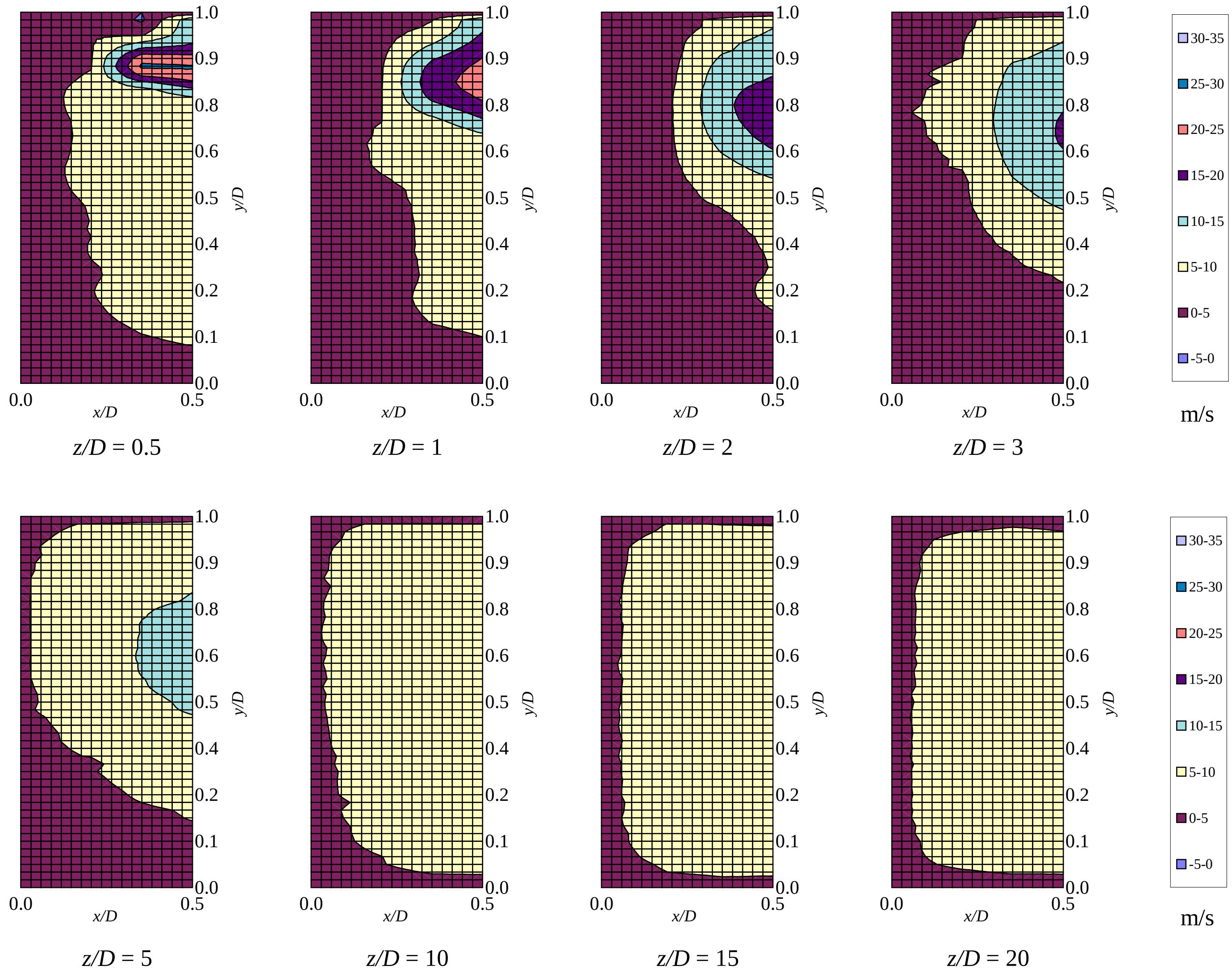

Fig.12 Velocity distribution in cross section with guide vane (open type 10 mm)

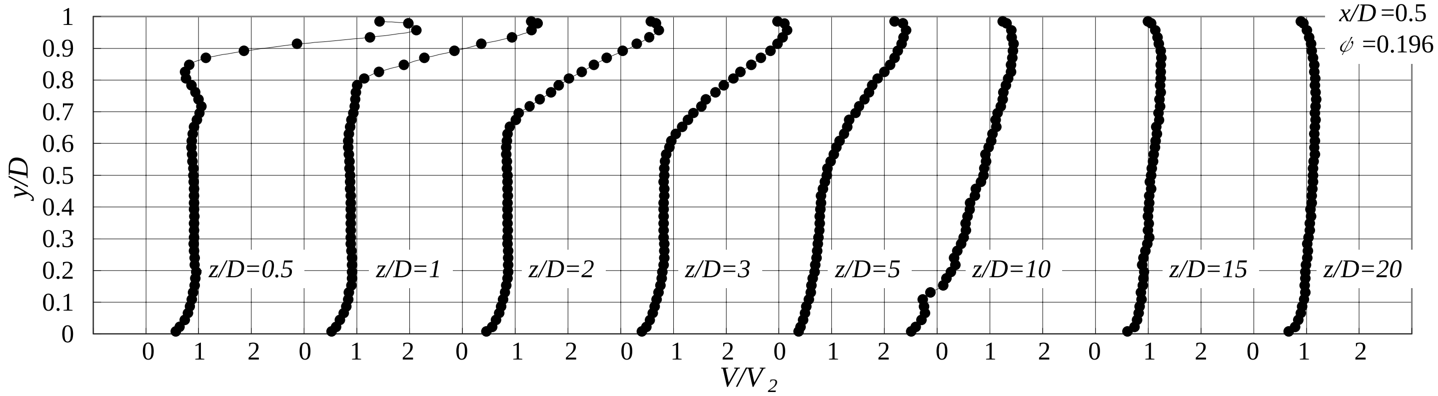

Fig.13 Velocity distribution in longitudinal section with guide vane (open type 25 mm)

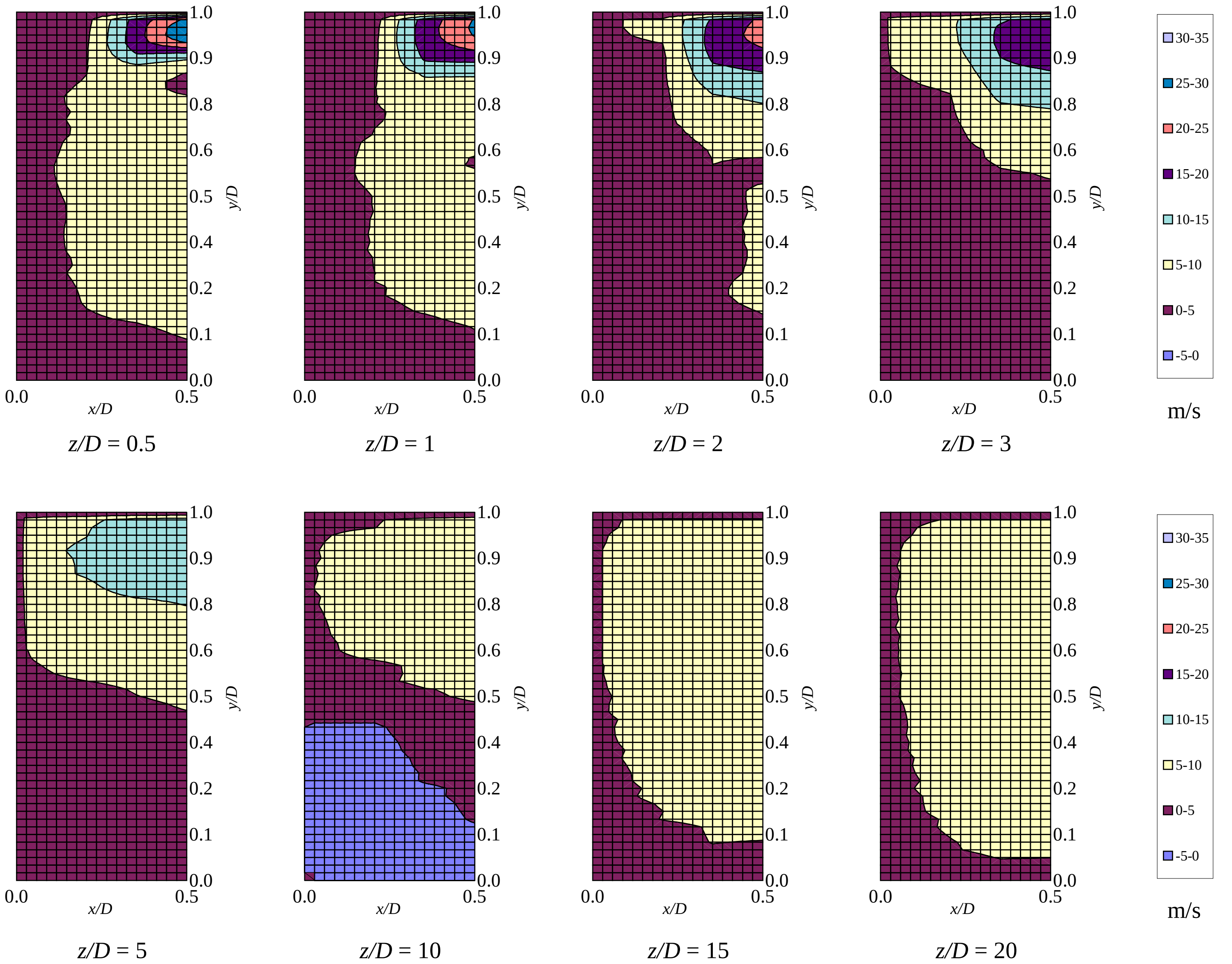

Fig.14 Velocity distribution in cross section with guide vane (open type 25 mm)