End Plates Effects on Drag Force of Vertical Flat Plates

by

Yoshinobu KUBO* and Kusuo KATO**

(Received November 30, 1984)

SYNOPSIS

It is discussed that the mechanism of drastic change of drag force corresponding to the diameter of end plates is not necessarily based on the loss of 2-dimensionality of air flow between end plates. The drag force coefficient is changeable depending on the diameter of end plates in the region up to 8 times of representative length of models. The drag force coefficient is $Cd = 2.23$ for vertical flat plate.

Introduction

End plates have been used to produce 2-dimensional air flow in investigation of 2-dimensional aerodynamic characteristics of the model for wind tunnel test.

End plates effects were pointed out by Nakaguchi[1]. According to his measurement of drag forces of square cylinders with end plates of various diameter, the drag force drastically increased with increment of diameter up to 8 times of the representative model length and it had constant value to the increment of end plate diameter in larger diameter than 8 times of the representative length of model. From these results, he recommended to use the end plates with diameter of 8 times of representative length of model. But he did not refer to the detail mechanism of this phenomena. After his research, the investigation about the mechanism was started by Takada[2] in terms of measuring the base pressure in the wake of vertical flat plate. He found the almost same results as Nakaguchi's and obtained the conclusion that the end plates effects were caused by the loss of 2-dimensionality of air flow in less diameter than 8 times of the representative length of model. His conclusion has no reasonable basis, because the base pressure of center point of model increases with the increment of end plate diameter and the calculated drag force from the measured base pressure by using the Maskel's[3] equation which was deduced by assuming 2-dimensionality of air flow around the model has the same tendency as that of measured drag force under the same conditions. This shows us that end plates effect is not necessarily caused by the loss of 2-dimensionality of air flow.

In this paper, the end plates effects are investigated from the view point of boundary layer interaction between wind tunnel walls and end plates and this investigation leads us to the answer of complicated results among the end plates effects, the supporting system condition of model and blockage effects.

Experiments

The vertical flat plates were set in the wind tunnel with square test section of 1070 × 1070

* Associate Professor, Dept. of Civil Eng.

** Assistant, Dept. of Civil Eng.

mm which is belonged to the department of Civil Engineering of Kyushu Institute of Technology. The model has the length of 750 mm between end plates and the various width from d=50 mm to 200 mm for investigation of relation of between drag and blockage effect. In the case of experiment of end plates effects, the model width was fixed d=40 mm and the diameter of end plates was changed from D=160 mm to 640 mm. The end plates of the model were set inner portion of 150 mm from walls in order to get rid of the influence of boundary layer of walls. The cover for the sensors which supported the model and measured the drag forces, had the shape of aerofoil because the non-aeronautical shaped(for example, cylinder)support gave the turbulent wake which caused the fluctuation of measured drag forces. In order to measure the base pressure of model, the pressure taps were set on the back side of the model. Fig. 1 shows the model and the model mounting system in wind tunnel.

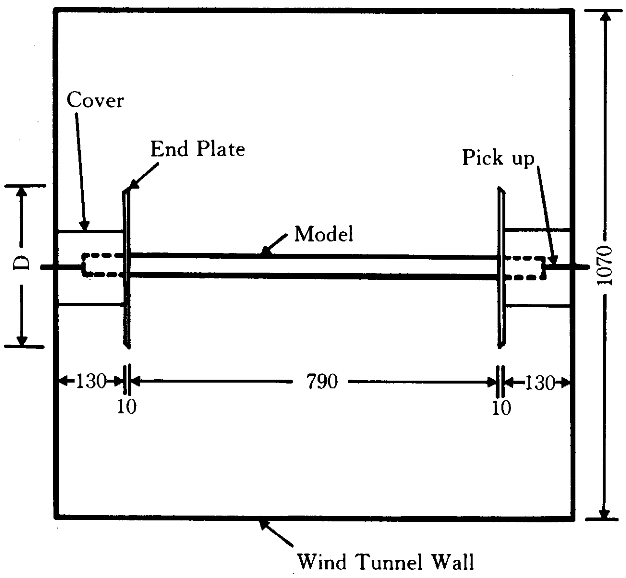


Fig. 1 Model and Mounting System of Wind Tunnel

Drag Forces and Blockage Effects

According to many experimental results, drag forces increases with increment of blockage ratio. But the drag forces has drastic change with increment of blockage ratio in the case of constant diameter of end plate. Fig. 2 shows this phenomena. In this case, the diameter of end plate has 450 mm and the width of model was changed from 50 mm to 200 mm, that is, blockage ratio was changed from about 4 % to 20 %. The efforts to find the causes of drastic change of drag forces were done to make clear the experimental accuracy from many view points. The significant points of them were the boundary layer effects on the wind tunnel walls and the fluctuation of measured value by the turbulence of the approaching flow. Although these were not main causes, the control of boundary layer on the tunnel walls was very important to increase the accuracy of drag force measurement. The method to control the boundary layer was to choose the aerofoil shaped cover as shown in Fig. 3. Fig. 4 shows the differences of measured drag forces between by both cases of the circular cylindrical cover and of the aerofoil shaped one. The drag force by the circular cylindrical cover flutuated over the testing wind velocity and its value was a little higher than that by the aerofoil one. This tells us that the flow characteristics of the outer region of end plates gives important influence to the aerostatic forces. The end plates effect was considered at last stage of this consideration as the answer of the drastic change of drag force in above mentioned conditions.

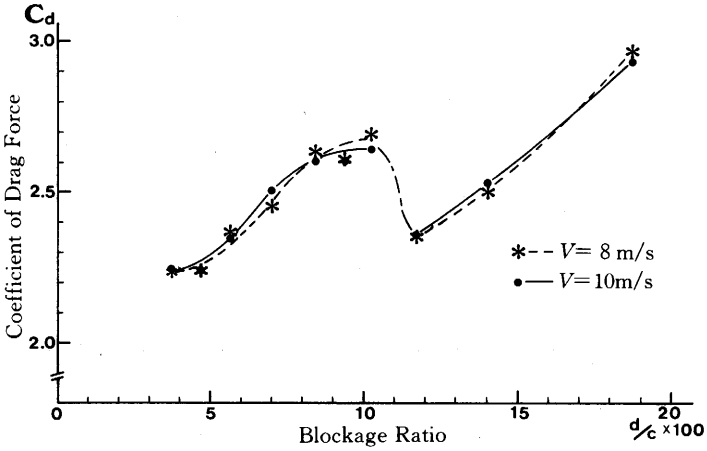
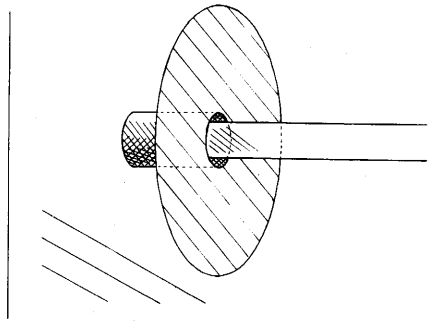
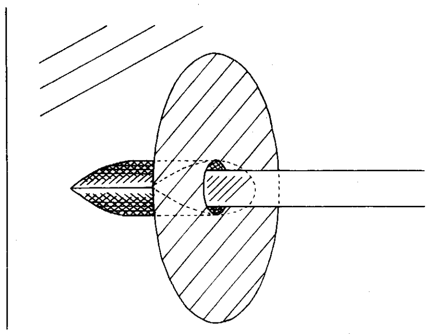


Fig. 2 Coefficient of Drag Force in Various Blockage Ratio with Diameter of End Plates of 450mm



(a) Circular Cylinder Cover



(b) Aerofoil Cylinder Cover

Fig. 3 Shapes of Covering Sensors and supporting End Plates

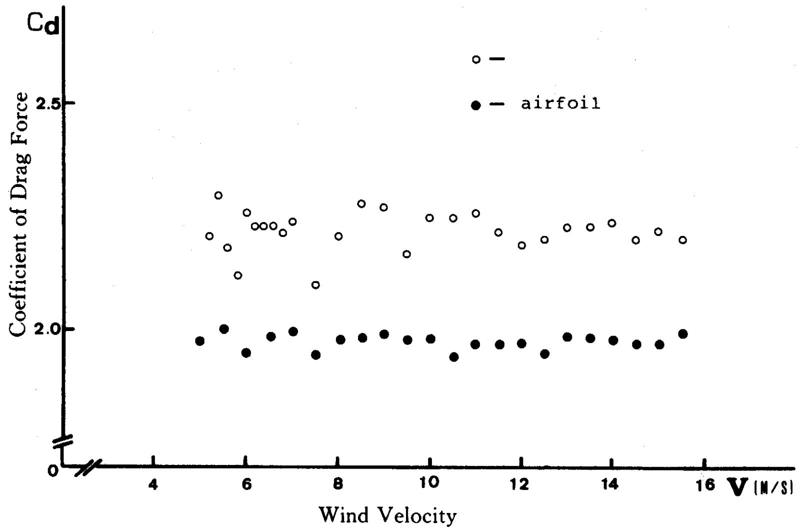


Fig. 4 Coefficient of Drag Force due to Circular Shaped and Aerofoil Cover of Support

The Drag Forces due to End Plates Effects

Nakaguchi's results tell us that the drag force is influenced by the size of end plates of model. The last investigation for the drastic change of drag force was whether the size of end plates of model is influenced on the value of measured drag force or not. On the basis of this consideration, the drag forces of vertical flat plate with width of 40 mm were measured by changing the diameter of circular end plates. Fig. 5 shows the result of measured drag force due to end plates effects. This curve (drag force coefficient 〔*Cd*〕 to end plate diameter ratio 〔*D*/*d*〕) shows that the drag force has drastic increment between 4.5 and 7.5 of end plate diameter ratio to the

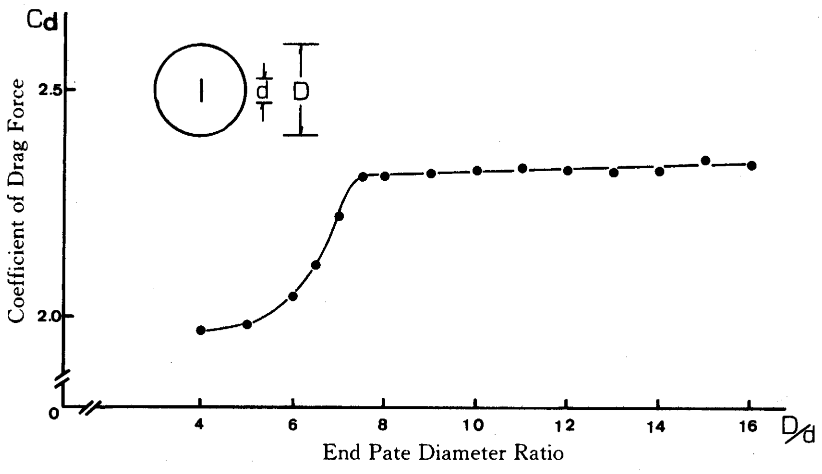


Fig. 5 Coefficient of Drag Force in various End Plate Diameter Ratio to Model Width

model width. The value changes from $Cd=1.9$ to 2.23 in this transient region which is middle region between $Cd=1.9$ 〔$D/d<4.5$〕 and $Cd=2.23$ 〔$D/d>7.5$〕.

Depending on this result, the mechanism of drastic change of drag force above mentioned is understood as that this phenomenon is the result of blockage effects added by the end plates as shown in Fig. 6.

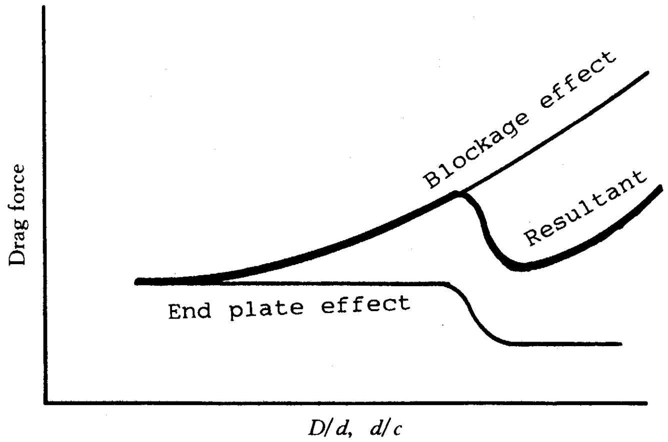


Fig. 6 Resultant Effects of Blockage and End Plates Effects

Distribution of Base Pressure

Is it true that Takada was pointed out that the causes of drastic change of drag force was based on the loss of 2-dimensionality of base pressure distribution ? Fig. 7 is the result of measured base pressure distribution of the model. According to this figure, the 2-dimensionality of

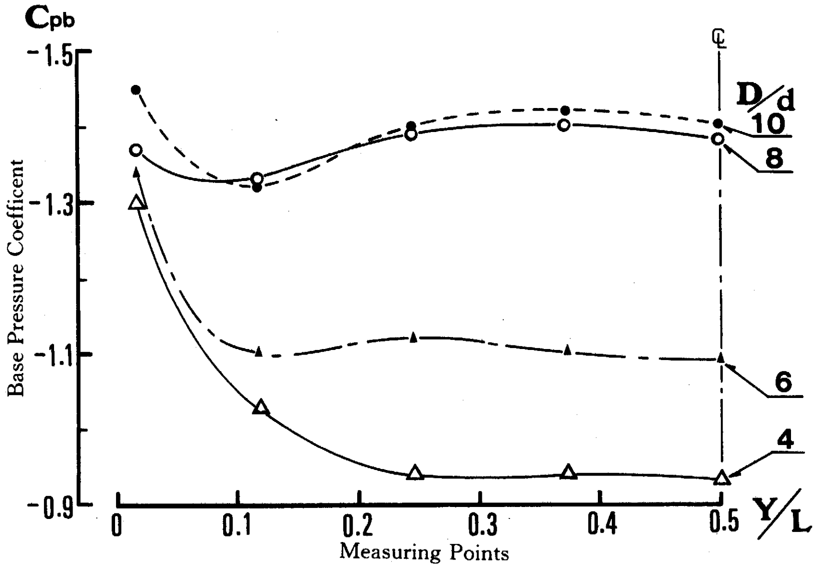


Fig. 7 Base Pressure Distribution for Various End Plate Radio (D/d= 4 , 6 , 8 , 10)

the pressure distribution seems not to be lost in the region of 75 % of center part of model for various each end plate diameter ratio 〔 D/d=4,6,8,10 〕. The diameter ratio D/d=6 has the most 2-dimensional characteristics of the pressure distribution in these diameter ratio. The tendency of the measured base pressure has the same as that of measured drag force for various end plate diameter ratio. The key point of consideration to the drastic change of drag force is to find the elemental causes of the phenomena. The drag force is the result of summing up the surface base pressure on the body, and the base pressure is produced by the velocity distribution around the body. The next measurement is the velocity distribution around body.

Wind Velocity Profile around Body

Figs. 8 to 11 show the results of measured wind velocity profile by using X-type hotwire anemometer, which are horizontal and vertical components of wind velocity at various points along the flow direction for diameter ratio of D/d=4 and 10. The distance 〔 X 〕 from model along flow direction is shown as the non-dimensional parameter of 〔 X/d 〕, and the distance 〔 Z 〕 perpendicular to flow direcition is shown as 〔 Z/d 〕. The measurements were done by using the traverse equipment drived by stepping motor, which gives high accuracy for setting the measuring position. Figs. 8 and 9 show the horizontal component distribution of wind velocity around vertical flat plate. In the case of D/d=4, the wind velocity profiles in the wake are nearly independent on the distance from the body, in the case of D/d=10, the value of wind velocity in the wake increases with increment of distance along flow direction. Referring to these figures, the more remakable formation of dead air region is done in the case of smaller diameter rather than larger one of end plates. If it is assumed that the best value of diameter for the end plates is the value in forming the dead air region in the wake of model because of that theoretical basis to analyze the drag force is put on the assumption of forming dead air region in the wake, the diameter must be smaller. But this consideration does not correspond to the necessity of end plate to produce the 2-dimensional air flow. Therefore, the end plates must have the diameter larger than 8 times of representative length of model.

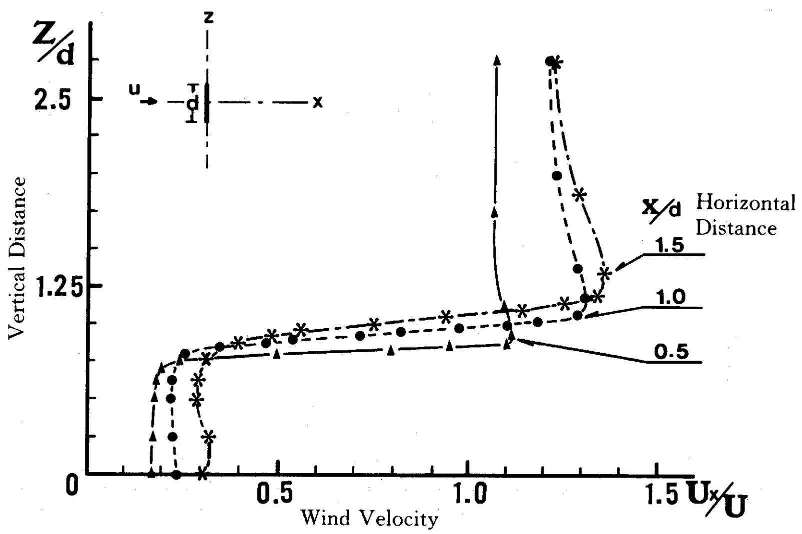


Fig. 8 Horizontal Component of Wind Velocity Profile in the Wake of End Plate Diameter Ratio (D/d= 4)

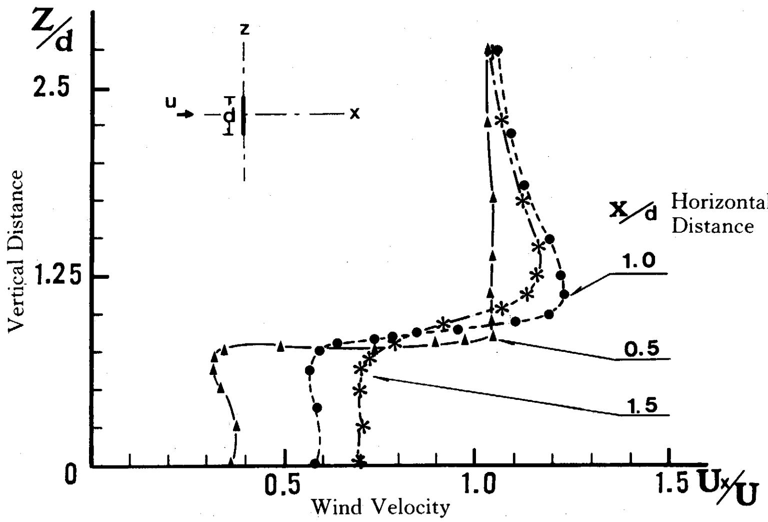


Fig. 9 Horizontal Component of Wind Velocity Profile in the Wake of End Plate Diameter Ratio (D/d=10)

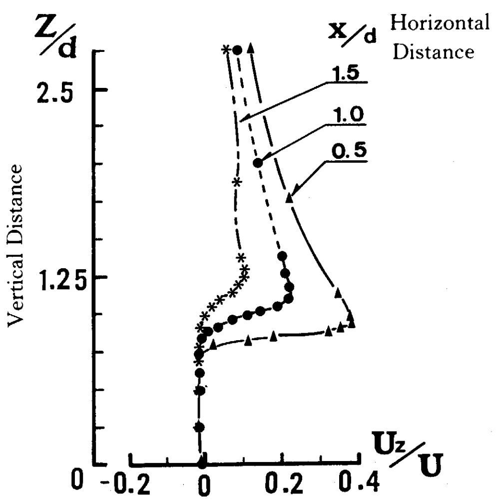


Fig. 10 Vertical Component of Wind Velocity Profile in the Wake of End Plate Diameter Ratio D/d= 4

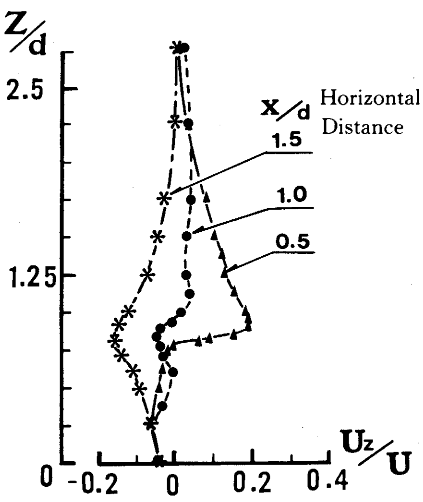


Fig. 11 Vertical Component of Wind Velocity Profile in the Wake of End Plate Diameter Ratio D/d=10

Figs. 10 and 11 show the vertical component distribution of the wind velocity in the wake. Although the value for the smaller diameter 〔 $D/d=4$ 〕 is independent on the distance from flat plate along the flow direction as well as horizontal component, the value for $D/d=10$ has the tendency of that the wind velocity in the wake at larger distance has the smaller value. The differences of the air flow charateristics in the wake between $D/d=4$ and 10 correspond to those of base pressure. But it is uncertain whether the loss the 2-dimensionality makes the drastic change of drag force as above mentioned or not. The boundary layer between wind tunnel walls and end plates is still considered as main causes for this phenomenon in considering with the method of controlling boundary layer by the shape cover.

Conclusions

The following conclusions are obtained from above investigations from a few different view points.

1) In any case where the static air force is measured, the diameter of end plates must be larger than 8 times of representative length of the model.
2) The drastic change of drag force which was observed in changing model width with end plate of constant diameter based on the compound effects of the blockage and end plates effects.
3) It is not reasonable to describe the drastic change of drag force to various diameter of end plates in the relation with the loss of 2-dimensionality of base pressure distribution between end plates.
4) Although the drag force coefficient of vertical flat plate is considered that it must be $Cd=2.0$ from theoretical investigation, according to present research, it is changeable from $Cd=1.9$ to 2.23 and the recommended value is $Cd=2.23$.

References

1) H. Nakaguchi, etal.; The Static Wind Pressure Load of Truss-structured Tower; Proceedings of Japan Society of Aeronautics, Vol. 12, No. 121, 1964(in Japanese).
2) H. Takada; Experiments on Wake of Vertical Flat Plate; Proceedings of Symposium on Experimental Study of Turbulence, 1968(in Japanese).
3) E. C. Maskell; A Theory of the Blockage Effects on Bluff Bodies and Stalled Wings in a Closed Wind Tunnel; R.A.E. report No. Aero 2685-A.R.C 25730, 1963.