Experimental study of flow past obstacles by PIV

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Abstract

The velocity field of flow past obstacles was surveyed by particle image velocimetry technique using 8μm Al₂O₃ powder as tracers. The flow field around the obstacles are obtained. The plots of the streamlines and the mean velocity field in horizontal and vertical sections are drawn. The vortex characteristics of wake flow in various flow field are investigated and compared. © 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/). Peer-review under responsibility of The Chinese Society of Theoretical and Applied Mechanics (CSTAM)

Keywords: flow around bluff body; PIV technique; streamline; wake flow

1. Introduction

Flow around obstacles is a typical flow separation, which is accompanied by flow separation, vortex formation and shedding, vortex interference, and many other basic theoretical issues [1]. A number of research focused on the structure of the vortex flow around a single obstacles [2]. There is few study on the influence of different shape to vortex structure

Particle image velocimetry (PIV) technology [3] is a kind of digital display technology for flow field, which breaks through the limitation of single point measurement techniques. It can obtain velocity vectors of several particles in the flow field at the same time. And also, PIV is a non-contact type measuring instrument with small disturbance to flow field, which has precision and fraction in single point measurement and also can obtain the overall structure and transient image of flow. So PIV is very suitable to study eddy, turbulence and other complex flow structure. Above all, in order to obtain the complete transient flow field around obstacles, PIV technology is a more effective tool.

A set of experimental equipment is designed and manufactured. The PIV testing system is developed for

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observing turbulent flow around obstacles. This paper describes the experiments of vortex structure in a flow around 7 types of obstacles using the PIV testing system, and reveals the influence of the shape of the obstacles and the slope to vortex development and structural characteristics.

2. Experimental techniques

A set of experimental equipment is designed and manufactured. A slope model was designed with three parts. The front part is a diversion slop for uniform flow. The obstacles are located at the center platform with 210mm length, 450 mm high. The last part at the downstream of small obstacles is a slope which sits at a 8-degree angle (θ=8°) to the bottom of the duct. The tunnel is 6.8m long, 0.1m wide and 0.2m high with flow rate of 2.5L/s. The tunnel model, slope and obstacles are made of organic glass in the experiment. The geometry of obstacles involved is shown in Fig.1. There are 7 kinds of obstacles numbered as A,B,C,D,E,F,G with the same height \( H=30\text{mm} \). In addition, Fig. 2 is shown to illustrate the layout of obstacles and slope in the water tunnel. PIV particles velocity measuring parameters are 200ns pulse interval, \( 248\mu\text{s} \) pulse delay, 32×32 pixels concerning area.

The experimental procedure is as follows.
(1) The slope model is fixed in the middle of the water tunnel and the obstacles are fixed on the platform of the slope model with fixed location.
(2) Open the pump and the inlet valve and regulate the tail gate to meet the flume requirement of the experiment.
(3) Let the water in the self circulation device operation for a period of time, in order to ensure water level of slope model consistent in the upstream and downstream.
(4) Check the test on the PIV measurement system. Particle imaging effect is investigated and the tracer particle concentration in the water is adjusted.
(5) One flow field is obtained by PIV measurement system with 20 pictures each sampling.
(6) Close the value, switch off the pump.
To measure other groups we only need to replace the obstacle on the platform, and then repeat step (2) to step 6).

3. Experimental results and discussion

The value of flow velocity \( (U_x) \) is 0.16m/s and the Reynolds number is about \( U_xH/\nu=3700 \), where \( H \) the height of the obstacles and \( \nu \) the water kinematic viscosity(10°C). The experiment results get form the plane of symmetry \((z/H=0)\).

Flow streamlines in the center section \((z/H=0)\) are presented in Fig.3. It is shown in the figure that one or a
few vortices are formed in the leeside of obstacles. Vortices in the leeside of model A and D are relatively smooth, while the rest of the vortex are disordered. There is a vortex behind model A and D and two vortices exist behind model B and E, respectively. The vortex structure behind model C,F,G is complex, but the main vortex can be visible clearly. Compared to the vortex occurred behind the obstacles on a flat surface, the vortices in this paper have the trend to the slope. This is due to the existence of the slope.

In the wake of cylinder most regions are showing reverse speed and have "a recirculation zone", which is consistent with the results of Ref.[4]. In this paper, the ratio of height to width is less than and equal to the critical value of 2 presented by literature[5]. The periodicity of the anti-symmetry vortex is suppressed. The wake is dominated by the downward flow from the top of the obstacles and the upwelling flow from the bottom is suppressed. At $H/d=3$, the rising flow in cylinder wake disappeared, which is the same as the results of Ref.[6].

In the wake region of C,F,G, there are nodes near the wall. These nodes are formed by the projection on the center side of the column section swept by shear flow. So flow near the nodes is three dimensional. There is a saddle point near the wall in the wake of model D.

Fig.3 Mean flow streamlines in the plane of symmetry ($z/H=0$)
In order to analyse quantitatively, mean streamwise velocity ($z/H=0$) at four location ($x/H=1.25$, $x/H=1.75$, $x/H=2.25$ and $x/H=2.75$) are present in Fig.4. As shown in Fig.4, the velocity curves of seven obstacles have the same trend. At the location of $x/H=1.25$, $x/H=1.75$, the velocity changes from 0 to a negative value and then back to 1, which indicate that the two locations are in the vortices. While at $x/H=2.25$ and $x/H=2.75$, the velocity in the $Y$ direction are all positive, which means the development of water has left the recirculation zone to the downstream area. It is worth to know that the velocity values of obstacle E in the four location are all positive, which shows vortices on the back of the obstacle E recovered fast. It is mainly due to the large gradient slope of the obstacle E. From the streamline chart of obstacle E in Fig.4 can be seen, two consecutive vortices appeared on the back of obstacle E. They are close to the wall and less impact on the mainstream.

The experimental reattachment length behind the obstacles are given in Table 1 respectively. From the table, it can be found that the length of recirculation region of obstacle C,E,F is relatively small, while which of obstacle A,B,D,G is bigger.

<table>
<thead>
<tr>
<th>Table 1 The reattachment length of vortex in the wake(Xr/H)</th>
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<td><strong>Obstacles</strong></td>
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<td>Experiments</td>
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4 Conclusion

The shape of obstacles affected location and size of the vortex behind the obstacles, especially the location. Compared with the case of obstacles placed in the plane, location of vortex in our experiment is closer to the slope. It is because of the influence of the slope.

Due to the aspect ratio of obstacles is less than the critical value presented by Sakamoto H [5], the wake is controlled by the drop flow skimming over the top of the obstacles and the upwelling flow at the bottom is inhibited.

The length of recirculation region of obstacle C,E,F is relatively small, while which of obstacle A,B,D,G is bigger. In short recirculation zone, flow is quickly recovered from the separation zone to the downstream development area.
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