NUMERICAL ANALYSIS OF FLOW CHARACTERISTIC WITH DIFFERENT CORNER RADIUS OF SQUARE CYLINDER

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The near wake of square section cylinders with different corner radii is studied by numerical method to investigate the influence of corner radius. Eight models, R/D=0, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5 (R is the corner radius and D is the characteristic dimension of the body) at Re=500 were studied. The numerical results of St , CD and CL at R/D=0 and R/D=0.5 were compared with experiments to prove the feasibility and also investigate the trend of flow phenomena by the various radius corners. Results indicate that, as R/D ratio is increased, the Strouha lnumber is increased, the minimum pressure point on the cylinder surface moved own stream. The calculated results shows that between R/D=0.15 to R/D=0.3 have lower CD and CL.

Key Words : Flow Induced Vibration, Votex Flow, Rounded Square Cylinder, Drag force, Lift force

1. INTRODUCTION

Over the last many years, flow around cylindrical bluff bodies has been subject of intense research, mainly owing to the engineering significance of structural design, flow induced vibration, and acoustic emissions, such as the design of tower structures, suspension bridges, chimneys, heat exchangers, flow meters, tall buildings, etc. The previous researches show that the section of cylinder is very important and many works of them focus on the circular and square section. Flow around various section cylinder is also been investigated.

Delaney and Sorensen (1953)[1] performed one of the earliest experimental studies on square and diamond cylinders with corner radius, as well as other cylindrical shapes. They showed that the drag coefficients of a sharp edged cylinder can be significantly reduced if the corners of the cylinder are rounded. Bearman et al (1984)[2] investigated the corner radius effect on the hydrodynamic forces on cylindrical bluff bodies. They found that the drag coefficient CD was sensitive to the corner radius in a steady flow and R/D=0.5 was not the smallest drag coefficient case.

S. Okamoto and N. Uemura(1991)[3] investigated the Effect of rounding side corners(2R/D=0, 0.157, 0.243, 0.5, 1) on aerodynamic forces. They found that the drag coefficient decreases rapidly in the range of R/D=0~0.3, and the Strouhal number for the arch vortex shedding increases as the radius of the corner increases. C. Dalton and W. Zheng (1999, 2003)[4-5] presented numerical results for a uniform approach flow past square and diamond cylinders. They noted that rounding corners of the bluff bodies produced a noticeable decrease in the calculated drag and lift coefficients. J. C. Hu et al (2005)[6] investigated flow around square cylinder with section of rounded corners by PIV. They gave a conclusion: The flow structure depends to a great extent on the corner radius of the cylinder, as R/D increases from 0 to 0.5, the maximum vorticity of the vortex attenuates, the circulation associated with vortices drops progressively by 50%; mean while, St climbs linearly by about 60%.

In present research, flow around square cylinder with rounded corners (R/D=0, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5) in 2 dimensional(2D) at moderate Reynolds number Re=500 will be investigated. It focuses on Drag coefficient and Lift coefficient, for the significant meaning for engineering practice.

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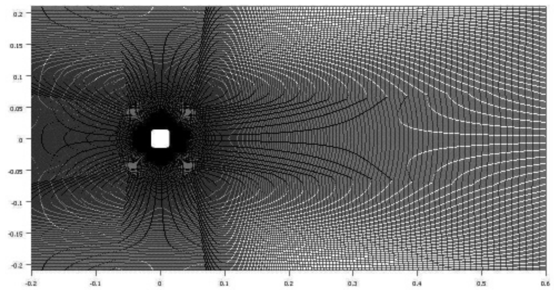
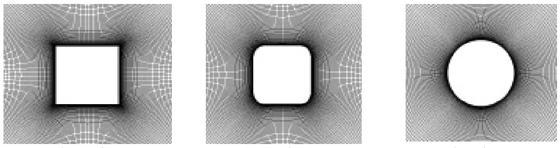


(a) Multi-block



(b) R/D=0 (c) R/D=0.2 (d)R/D=0.5

Fig.1 Grid systems

2. VALIDATION OF NUMERICAL METHOD

Consider a 2 D flow of viscous incompressible fluid with dynamic viscosity v and a constant velocity U_0 past a square cylinder. The only incompressible flow parameter Reynolds number Re=U_0D/v=500. Even though the wake at Re=500 is not laminar, no turbulence model is included. For our purpose is to compare the effects of rounding of the corners of cylinder, CFD ACE(A commercial code) is employed. A second order scheme Crank Nicolson for time and 2nd UPWIND scheme for space are adopted. Multi block is used to generate non uniform structure grid system, as show in fig.1. The computational domain is 7≤X/D≤20 and 7≤Y/D≤7, as show in fig. 1. The inlet boundary condition is used with uniform velocity, and the outlet boundary is set with pressure=0. The top and bottom side are considered as symmetry.

Grid dependence is showed in table 1. Strouhal number

Table 1 Grid dependence

Grid NO.	S_t	C_D (Mean)	C_L(R. M. S.)
110x70	0.1259	1.88	0.702
160x120	0.1272	1.955	0.975
220x180	0.1329	1.81	0.903
280x200	0.13445	1.76	1.09
300x220	0.13446	1.758	1.09

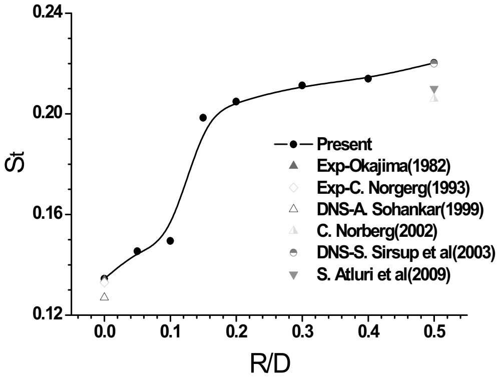


Fig.2 Strouhal number

S_t=fD/U_0,, which D is the characteristic length (cross direction length of cylinder), f is the frequency of u (velocity in flow direction) at point (5D, 1.5D). U0 is the uniform flow velocity. Because of the sharp square (R/D=0) case is more difficult to convergence than others (W. Zhang and C. Dalton, 1998)[4], just sharp square case is showed here.

It looks that 280x200 is enough for present research.

3. RESULTS AND DISCUSSION

3.1 STROUHAL NUMBER

The calculation of flow past cylinder was carried out with corner radius R/D=0, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5. The corner radius affects the shedding frequency and wake flow near the cylinder.

Figure 2 shows the S_t as the R/D is increased. A. Okajima(1982)[7] and C. Norberg(1993)[8] tested the flow after sharp square cylinder with experiments. They got S_{tt}=0.13 at Re=500 respectively. Sohanker et al(1999)[9]got S_t=0.126 by DNS(Direct numerical simulations). In present simulation, we get S_t=1.34, which has a good agreement with experiment and DNS results as mentioned above. In the circular cylinder case, calculated S_t= 0.22 which is also good agreement with previous results given by C. Norberg(2003)[10], S. Atluri et al(2009)[11]and S. Sirsup et al(2003)[12]. The S_t of R/D=0.5 case is about 60% higher than R/D=0 case. As the R/D is increased, St is increased and a drastic change occurs in the R/D=0.1~0.15. It agreements with the conclusion that the Strouhal number is increased by rounded corners which is given by Tetsuro Tamura and Tetsuya Miyagi (1999)[13].

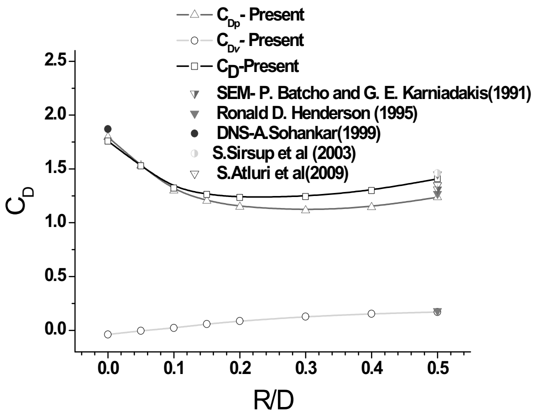


Fig. 3 Time mean of drag force coefficient

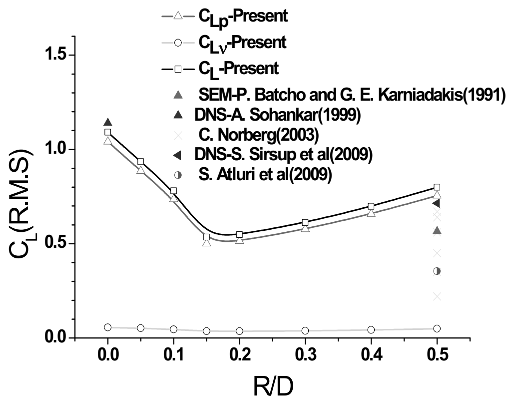


Fig. 4 Root mean square of lift force coefficient

3.2 Drag and Lift Coefficient

Fig. 3 shows the mean drag coefficient C_D, mean pressure drag coefficient C_{Dp} and mean viscous drag coefficient C_{Dv}. It shows that the drag C_D is mainly caused by the pressure difference between foregoing surface and rear surface of cylinder, high C_D means that high time mean pressure difference. In R/D=0~0.15, the C_D decreases about 30% rapidly which is agreement with S. Okamoto and N. Uemura(1991)[3] who found that the drag coefficient decreases rapidly in the range of R/D=0~0.15 by experiment. In R/D=0.15~025, C_D decrease pretty slightly as R/D increase. In R/D=0.25~0.5, the C_D increase about 12% as R/D increase. Totally for R/D=0~0.5, the drag force decrease about 20%. Pressure drag coefficient C_{Dp} has same trend with C_D and the minimum value occurs at R/D=0.2~0.3. It agrees with Bearman et al(1984)[2] who showed that the lowest drag coefficient is at R/D=0.265 in oscillatory flow by experiment. The value of C_{Dp} larger than C_D in R/D=0~0.05 and less in R/D=0.05~0.5. It's due to the mean viscous drag coefficient C_{Dv} nearly linearly increases from negative to positive and equals to 0 at R/D=0.05. The calculated results C_D=1.76, C_{Dp}=1.8 agree with the DNS result C_D=1.87 by Sohankar et al (1999)[10] on flow after sharp square cylinder. The C_D=1.41, C_{Dp}=1.24, C_{Dv}=0.17 of circular cylinder R/D=0.5 fit the high resolution computer simulation results C_D=1.45, C_{Dp}=1.27, C_{Dv}=0.18 by Ronald D. Henderson(1995)[14] and C_D=1.3 by Robert and D.Blevins(1990)[15], as well as DNS results C_D=1.35 by S.Atluri et al(2009)[12], C_D=1.46 by S. Sirisup et al(2004)[13] and C_D=1.31(2-D), 1.17(3-D) by SEM(Spectral element method) by P. Batcho and G. E. Karniadakis(1991)[16].

The root mean square of total lift coefficient C_L, pressure lift coefficient C_{Lp}, viscous lift coefficient C_{Lv} are shown in Fig. 4. All of them have same tendency. They decrease rapidly about 50% as R/D increase in R/D=0~0.15which agrees with T. Tamura and T. Miyagi(1999)[13] who used experiment method to get that the root mean square of total lift coefficient can be reduced to about 50% by rounding corners R/D=1/6. In R/D=0.15~0.5, They increase about 50%. Totally they decrease 30% in R/D=0 ~0.5. The maximum values appear at R/D=0, which C_L=1.09, C_{Lp}=1.04, C_{Lv}=0.055 and the minimum points are at 0.15<R/D<0.2. The C_L=1.09 at R/D=0 agrees with DNS result C_L=1.14 by Sohankar et al (1999)[10]. In circular case, C_L=0.566(2-D), 0.23(3-D) are got by P. Batcho and G. E. Karniadakis(1991)[16] by SEM(spectral element method). DNS results C_L=0.35 by S.Atluri et al(2009)[11]and C_L=0.85by S. Sirisup et al(2004)[12], which are agreed by present result C_L=0.80.

Based on both C_D and C_L, we can find that the rounded corners can obviously reduce the drag and lift force and the lowest value are in R/D=0.15~0.2.

3.3 Vortex Formation Length

Fig. 5 shows the calculated mean velocity u along centerline. As R/D is increased, the vortex formation length is increased in R/D=0~0.1 and decreased in R/D=0.1~0.5 (Fig. 6).

3.4 Wave Width

The fig. 7 shows the mean vorticity at X/D=1. Wave width is got in fig. 8, which shows that the wave with decrease quickly in R/D=0~0.2 and nearly no change in R/D=0.2~0.5.

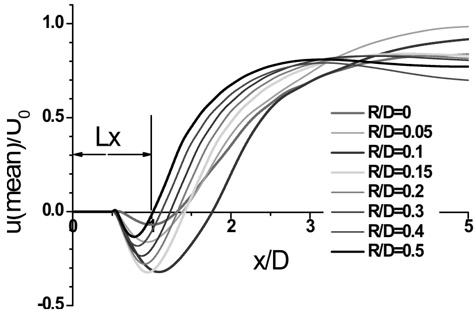


Fig.5 Mean velocity u along centerline

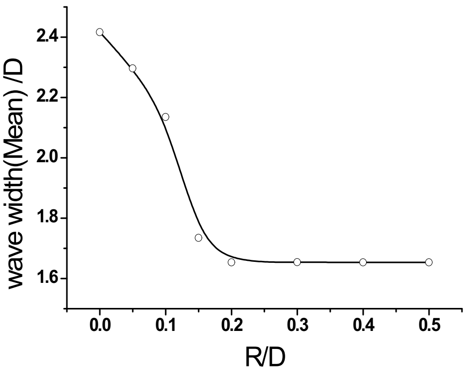


Fig. 8 Time Mean wave width

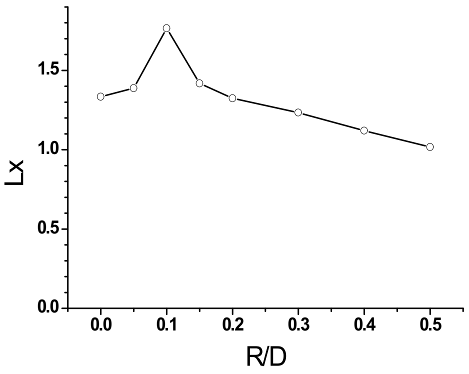


Fig.6 Vortex formation length with R/D

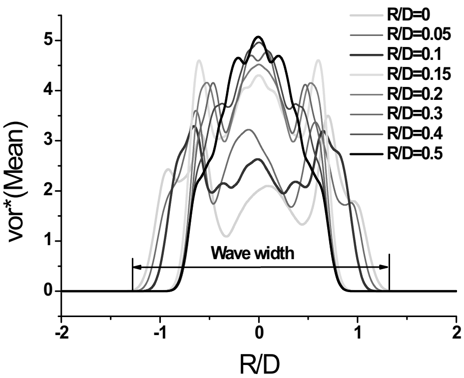


Fig. 7 Mean normalized vorticity(Vor*=vorticity*D/U_0)

4. CONCLUSIONS

The near wake of square section cylinders with different corner radii is studied by numerical method to investigate the influence of corner radius. Eight models, R/D=0, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5 (R is the corner radius and D is the characteristic dimension of the body) at Re=500 were studied. The numerical results of St, CD and CL at R/D=0 and R/D=0.5 were compared with experiments and DNS results to prove the feasibility and also investigate the trend of flow phenomena by the various radius corners. Results indicate that, as R/D ratio is increased, the Strouhal number is increased and have a drastic increase in R/D=0.1~0.15. The minimum pressure point on the cylinder surface moves downstream. The calculated results show that between R/D=0.15 to R/D=0.2 have the lowest CD and CL. Also vortex formation length and wave length are showed. Both of them have greatly changes on their gradients in R/D=0.15~0.2.

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