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Numerical studies on spacing ratio effects of two tandem square cylinders with different chamfered-corner ratios

Jingmiao Shang[1], Qiang Zhou[2,3], Qinhua Wang[4]

[1]School of Civil Engineering and Architecture, Southwest University of Science and Technology, Mianyang, China, mervin@swust.edu.cn
[2]Research centre for Wind Engineering, Southwest Jiaotong University, Chengdu, China, milan1023@gmail.com
[3]Key Laboratory for Wind Engineering of Sichuan Province, Chengdu, China, milan1023@gmail.com
[4] School of Civil Engineering and Architecture, Southwest University of Science and Technology, Mianyang, China, gbqhwang@swust.edu.cn

SUMMARY:
Three-dimensional large eddy simulations (LES) were carried out to investigate the flow past a pair of tandem square cylinders with different spacing ratios of $L/D = 1.25, 2, 4, 6$ and different chamfered-corner ratios $\xi = B/D = 0\%, 5\%, 10\%, 15\%$, where L is the cylinder centre-to-centre distance between the cylinders, D is the cylinder width and B is the chamfered corner dimension. The Reynolds number is 5.3×10^3. The focus is given on how L/D and ξ influence the flow structure, wake recirculation bubble, flow separation bubble, Strouhal number (St), aerodynamic force, and phase lag (ϕ) between vortex shedding from two tandem square cylinders. An interesting finding is that the chamfer modification may cause the flow structure to change prematurely at smaller critical spacing ratio. This will lead to a sudden change in the aerodynamic force of the cylinders. With different ξ, St has a different trend with increasing L/D, indicating that the flow structure may have changed prematurely.

Keywords: tandem square cylinders, chamfered-corner modification, spacing ratio

1. GENERAL INSTRUCTIONS

It is well known that the flow around two tandem cylinders without corner modifications is highly complicated and sensitive to spacing between the cylinders, extensively investigated in the literature (Sakamoto, et al., 1987; Sohankar, 2014; etc.). The effect of the corner chamfer ratio on the flow of two tandem square cylinders has been investigated in the author's previous research (Shang, et al., 2019). The motivation of this paper is to understand the interference effect change with separation spacing between two tandem cylinders with modified corners.

2. METHODS

2.1. Numerical discretization and algorithm

In the simulation, the velocity and pressure are defined at the centre of a control volume, while the volume fluxes are defined at the midpoint of their corresponding cell surfaces. The momentum interpolation method is used to avoid oscillating problems by eliminating the checkerboard pressure and subsequent refinements with a non-staggered mesh. In addition, the Fractional Step Method (FSM) algorithm is utilized. The residual tolerance of the non-iterative solver controls of pressure and momentum are set to 1×10^{-9} and 1×10^{-8}, respectively.

To avoid the instability caused by central-differencing schemes and non-physical wiggles, the bounded central differencing scheme is applied for spatial differencing of the convection term, which is a composite normalized variable diagram scheme consisting of a pure central differencing scheme, a blended scheme of the central differencing scheme and the second-order upwind scheme, and the first-order upwind scheme. A fully implicit second-order time-advancement scheme is chosen for temporal discretization to obtain a stable and accurate simulation.

2.2. Computational domain and boundary conditions

As shown in Figure 1, the computational domain size is 45D in the x-direction, 20D in the y-direction and 4D in the z-direction, where the cylinder centre-to-centre distance is L = 1.25D/2D/4D/6D and the blockage ratio is 5%.

The structured O-type grid systems with the depth of the first grid near the body surface with an empirical value of $0.1/\sqrt{\mathrm{Re}}$ are applied to adequately resolve the flow. For more efficient simulations, the computational domain is spatially resolved such that a dense clustering of grid points is applied near the wall. For the temporal discretization, the non-dimensional time-step is 5×10^{-5}, which maintains the maximum Courant number below 1.

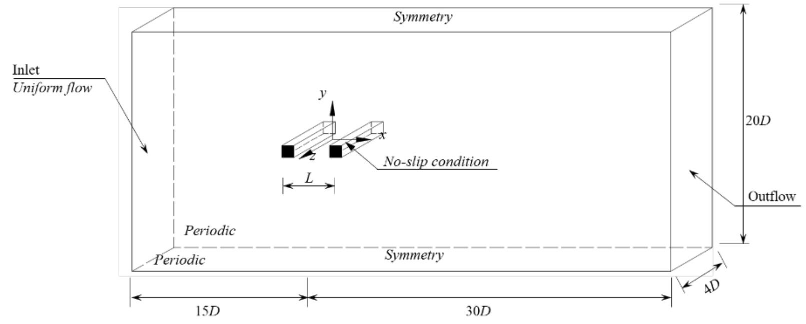

Figure 1. Computational domain and boundary conditions.

2.2. Computational domain and boundary conditions

To validate the present simulation, table 1 compares firstly the basic aerodynamic parameters of a single square cylinder at Re = 2.2×10^4 obtained presently with those from previous numerical and experimental studies. The cell number for single cylinder in present study is about 1.4 million. The aerodynamic parameters (Strouhal number St, time-mean drag coefficient $\overline{C}_D$, fluctuating lift coefficient C'_L) are all normalized by D and/or U_∞.

Table 1. Integral parameters of a single square cylinder.

	Re	$\overline{C}_D$	C'_L	St
Present (LES)	2.2×10^4	2.239	1.365	0.125
Tamura, et al., 1998 (Exp.)	3.0×10^4	2.090	1.050	0.128
Sohankar, et al., 2000 (LES)	2.2×10^4	2.320	1.540	0.132

For the statistical average, the time sample was about 30 vortex shedding periods which is more than the suggestion of (Cao and Tamura, 2016). As shown in the Table 1, some values differ somewhat because of Re differences. Overall, a good agreement of the present data is achieved with previous studies.

3. RESULTS AND DISCUSSION

3.1. Flow structures

The flows around the two cylinders with different spacing ratio L/D and different corner ratio ξ are examined, providing an insight into the effects of L/D and ξ on flow structures and basic aerodynamic parameters. The flow structures are presented in terms of instantaneous vortices and the time-mean streamlines as shown in Figure 2 and Figure3.

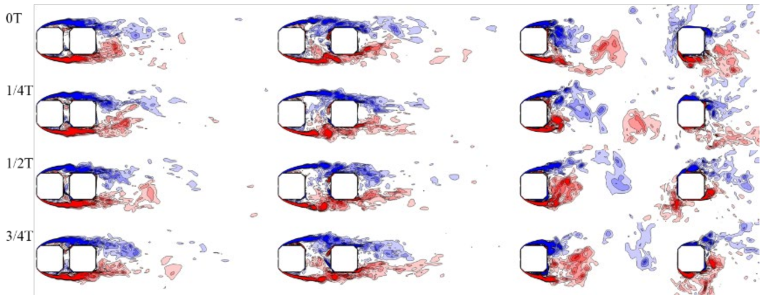

Figure 2. Instantaneous spanwise vorticity contours in the cases of ξ = 15% for different *L/D*.

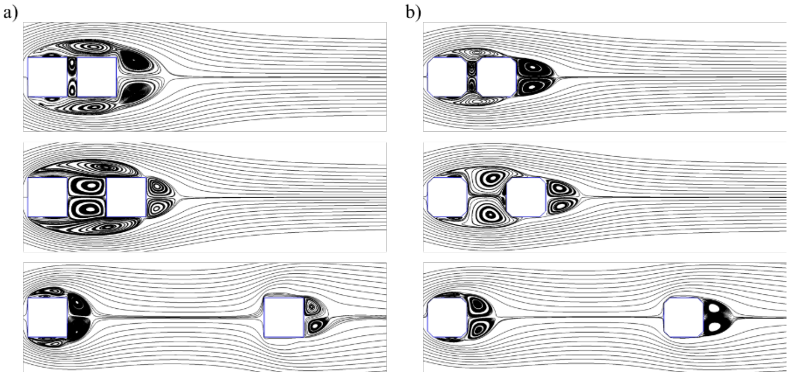

Figure 3. Mean streamlines of the flow two cylinders for different *L/D*: a). ξ = 0% and b). ξ = 15%.

3.2. Aerodynamic forces

Figures 4 compares the distribution of the time- and spanwise-averaged pressure coefficient along the top half circumferences of the downstream cylinders.

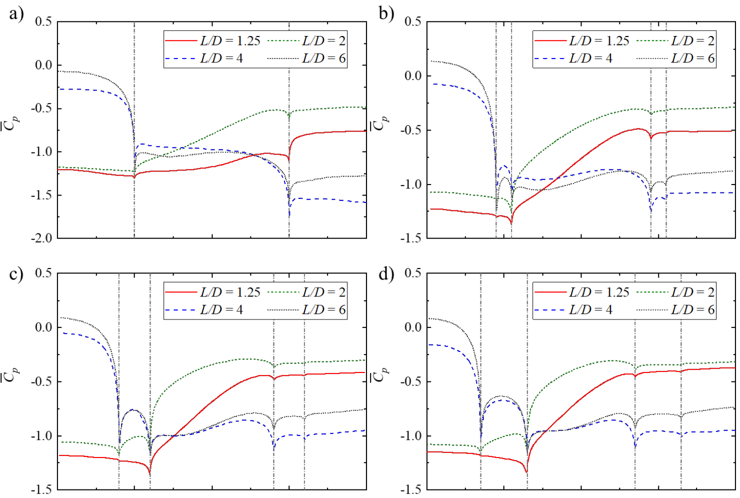

Figure 4. Mean pressure coefficient distributions along the surfaces of downstream cylinder for different *L/D*: a). ξ = 0%, b). ξ = 5%, c). ξ = 10% and d). ξ = 15%.

3.3. Strouhal number

With different ξ, St has a different trend with increasing *L/D*, indicating that the flow structure may have changed prematurely. More details will be discussed in full text article.

7. CONCLUSIONS

This paper focuses on the effects of corner chamfers and spacing ratio on the flow past two square cylinders in tandem. 3D LES is used and mainly mean and RMS flow quantities are reported and analyzed. In the abstract, some statistical flow and aerodynamic properties are presented as follows:

a. When *L*/*D* = 4 as the representative of the co-shedding flow, the mean pressure distribution along the surfaces of downstream cylinder is similar, which is slightly reduced as *L*/*D* increased.

b. The chamfered-corner may cause the flow structure to change prematurely at smaller critical spacing ratio of *L*/*D*<4.

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REFERENCES

Sakamoto, H., Hainu, H., and Obata, Y., 1987. Fluctuating forces acting on two square prisms in a tandem arrangement. Journal of Wind Engineering and Industrial Aerodynamics 26, 85–103.

Sohankar, A., 2014. A LES study of the flow interference between tandem square cylinder pairs. Theoretical And Computational Fluid Dynamics 28, 531–548.

Shang, J., Zhou, Q., Alam, M. M., Liao, H., and Cao, S., 2019. Numerical studies of the flow structure and aerodynamic forces on two tandem square cylinders with different chamfered-corner ratios. Physics of Fluids 31, 075102.

Cao, Y., and Tamura, T., 2016. Large-eddy simulations of flow past a square cylinder using structured and unstructured grids. Computers & Fluids 137, 36-54.

Tamura, T., Miyagi, T., and Kitagishi, T., 1998. Numerical prediction of unsteady pressures on a square cylinder with various corner shapes. Journal of Wind Engineering and Industrial Aerodynamics 74–76, 531–542.

Sohankar, A., Davidson, L., and Norberg, C., 2000. Large Eddy Simulation of Flow Past a Square Cylinder: Comparison of Different Subgrid Scale Models. Journal of Fluids Engineering 122, 39.