Experimental Study on Interference Effects of Two Tandem Cylinders Wrapped Around by Triple Helical Rods with Gap on Induced Drag

R.W. Prastianto	extsuperscript{1a}, K. H. Dwipayana	extsuperscript{1b}, N. Syahroni	extsuperscript{1c} and B. Pumbarino	extsuperscript{1d}

	extsuperscript{1}Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo Surabaya (60111), Indonesia


\textsuperscript{a}rudiwp@oe.its.ac.id, \textsuperscript{b}khdwipayana@gmail.com, \textsuperscript{c}nur.syahroni@gmail.com, \textsuperscript{d}pumbarino@gmail.com

Abstract. This paper examines the results of laboratory experiments to investigate the effect of interference of two tandem cylinders covered by triple helical rods with gap to the induced drag force. Two identical rigid models are horizontally positioned with roll support on both ends of each cylinder. Uniform air flow in subcritical regime that correspond to Reynolds number (Re) of $1.6 \times 10^4 \sim 6.5 \times 10^4$ perpendicularly flowed to the models in the wind tunnel with three variations of the distance between the cylinders which are 1.75D, 3D and 5D. At Re $= 4.2 \times 10^4$ the results show that the maximum shielding effects occur in the rear cylinder at the distance of 1.75D so the drag coefficient ($C_D$) is reduced to 93.6% compared to single cylinder case. This shielding effect will weaken with increasing the distance between the cylinder. In contrast, the fluid flow interference effect on the front cylinder increases due to increasing of spacing between the two cylinders and still occurred at that spacing of 5D until $C_D$ reduction reached 10% of the single cylinder case.

Keywords: Triple helical rods with gap, Drag coefficient, Tandem configuration, Interference effects.

1. Introduction

Conductors, raisers and jacket legs of offshore platforms are cylindrical structures that generally receive the load of current during their operation. The current load on a certain Reynolds numbers will evoke the phenomenon of Vortex Induced Vibration (VIV). Such structures are generally installed in an array that allows interference of their vortex flow caused by the current.

The classification of fluid flow interference is given by Zdravkovich [1] where tandem configuration is classified as wake interference. Pappaioannou, et al. [2] examined the interference of two bare cylinders through numerical study. The results show that the mean drag of the front cylinder is always greater than the rear cylinder in all cases of reduced velocity and distance variations. This caused by shielding effect.

Previously, experimental studies on the VIV of free-hanging cantilever cylinder already done by Prastianto, et al. The studies covered a single, two cylinders in tandem, side-by-side and staggered configurations and three cylinders in a group cases. In all the case studied drag and motion amplitude of the cylinders were evaluated as well as wake interference effects to the cylinders responses [3, 4, 5, 6].

Helical rods as a suppression device were reviewed by Zdravkovich [7] which is the one solution to reduce VIV. Then Sugiwanto, et al. [8] found the optimum configuration for the triple helical rods with gap through a numerical study, i.e. with a rod diameter of 0.0625D where D is the diameter of the cylinder. Referring to the Sugiwanto, et al. [8]; Prastianto, et al. [9] proceed it with laboratory experiments and the results indicated that the device is able to reduce the drag force up to 50.0% at Re $= 2.36 \times 10^4$ compared to the single cylinder case.
This paper presents the effect of interference of two rigid cylinders covered by triple helical rods with gap to the drag force at Reynolds number of $4.2 \times 10^4$ due to variation of the distance between them. The results are validated and evaluated to previous relevant study which conducted on multiple tandem bare cylinders [11].

2. Experimental Method

Cylinders of the model are made of aluminum tube with diameter (D) of 5.08cm and 48cm in length (l). While the rods with diameter (d) of 0.3cm are made of stainless steel wire. The rods are helically wrapped around on each cylinder in triple configurations with 0.0625D gap (g) as depicted in Figures 1 and 2.

![Figure 1. The model of cylinders wrapped around by triple helical rods with gap](image)

![Figure 2. Two dimensional illustration of the experiment](image)

Experiments were performed in Low Speed Wind Tunnel (LSWT) with 0.5m × 0.5m × 1.25m test section size with the model are horizontally installed in tandem arrangement. The tunnel belongs to a laboratory of BBTA3, Agency for the Assessment and Application of Technology (BPPT), South Tangerang, Indonesia. The test used three variations of center-to-center distance (L) between the cylinders which are 1.75D, 3D and 5D, respectively. Direction of in-coming air flow is perpendicular to the model at speed range of 5m/s ~ 20m/s that correspond to Re of $1.6 \times 10^4$ up to $6.5 \times 10^4$. Detail of the experiment is explained in Prastianto et al. [12]. Load cells for measuring drag are installed at the all ends of the model cylinders which is supported by special frame as roll supports (see Figures 2 and 3).

3. Results and Discussions
Validation of the experiment was done by comparing the drag coefficient \( (C_D) \) for the case of single bare cylinder at tested range of Re to the relevant reference data [10]. The result showed a very good agreement at Re range of \( 3.5 \times 10^4 \) up to \( 4.8 \times 10^4 \) as shown in Figure 4. Thus the model could be used for further intended cases at such Re range. The analysis in the present paper is focused for \( Re = 4.2 \times 10^4 \). At relatively low Re, the measured drag were smaller than the reference data which is may caused by unstable flow speed generated in the test section by propeller system of the tunnel at very low rotation frequencies.

Figure 3. The model installation in the test section (e.g. for a case of \( L/D = 5 \)).

Figure 4. Validation of the experiment.

Figure 5 shows the experiment result of \( C_D \) of the two cylinders at \( Re = 4.2 \times 10^4 \). For all three variations of the distance between the cylinders \( (L/D) \), \( C_D \) of the rear cylinder are smaller than that of the front cylinder which are 0.07, 0.23 and 0.55, respectively. The lowest \( C_D \) (at a value of 0.07) is due to strong shielding effect onto the rear cylinder caused by existence of the front cylinder that occurs at the \( L/D = 1.75 \). The rear cylinder was almost totally covered from the incoming flow that in turn caused a significant reduction on the \( C_D \) of about 93.6% compared to the \( C_D \) of single cylinder with
helical rods. Such shielding effect will gradually weaken with increasing the distance between the cylinders that caused the $C_D$ gradually increased and became 0.55 at $L/D = 5.0$.

Meanwhile, interference effect of the fluid flow around the cylinders also causes reduction on $C_D$ of the front cylinder. $C_D$ of the front cylinder at $L/D = 1.75$ is 1.06 that slightly decreased of about 2.5% from the case of single cylinder with helical rods. This reduction slightly increase due to increasing the distance between cylinders. At $L/D = 5.0$ the flow interference around the two cylinders still occurred which causes reduction on $C_D$ of the front cylinder by about 10% compared to the $C_D$ of the single cylinder with helical rods.

![Figure 5. Drag coefficient ($C_D$) of the cylinders for present study.](image)

The result of the present study has also been compared to the relevant existing data such as given by Igarashi on Kitagawa, et al [11]; Zdravkovich, et al on Kitagawa, et al [11] and Kitagawa, et al [11] (see Figure 6). All these previous studies were also investigating the characteristics of drag and flow around circular cylinders in tandem arrangement but for bare cylinders cases and were performed at subcritical Reynolds number ($2.2 \times 10^4$, $3.1 \times 10^4$, and $3.55 \times 10^4$) that are comparable to the present study. Generally, the comparison showed a good agreement of $C_D$ at almost all of the distance variation ($L/D$) tested. Slight differences on the $C_D$ of the present study to the other data may caused by the existance of the additional triple helical rods on the cylinders.

4. Conclusions

In the tandem arrangement of two cylinders, the front cylinder causing a shielding effect to the rear cylinder for certain spacing between them and fluid flow interference from around the two cylinders resulting in reduction of the drag coefficient of the rear cylinder. The largest reduction occurred for the distance between cylinders of 1.75D by about 93.4%. This shielding effect decreased (that means the drag coefficient increased) with increasing the spacing between the cylinders. At the same time, in contrast, drag coefficient of the front cylinder gradually decreased as the spacing between the cylinders increasing and reached a largest reduction of 10% at the spacing of 5D. At this spacing the flow interference around the two cylinders still occurred. In the present study, the increase of the $C_D$ of
the rear cylinder occurred much more drastic than that the reduction of the $C_D$ of the front cylinder as the spacing between the cylinders increased.

![Figure 6](image)

**Figure 6.** Comparision of the present study to the relevant existing data.

**Acknowledgements**

The authors wish to thank Directorate General of Higher Education (DIKTI) – Ministry of Research, Technology and Higher Education, Republic of Indonesia for the financial support through a research grant scheme of “Penelitian Unggulan Perguruan Tinggi (PUPT)” 2016. Also thanks to Institute for Research and Community Services (LPPM) – Institut Teknologi Sepuluh Nopember (ITS) Surabaya for the assistance and guidance. All contributions from National Laboratory for Aerodynamics, Aeroelastics and Aeroacoustics Technology, Agency for the Assessment and Application of Technology (BPPT), Indonesia, are highly appreciated.

**References**

[1] Zdravkovich, M. M. (1987). The effects of Interference between circular cylinders in cross flow. *Journal of Fluids and Structures*, 239-261.

[2] Pappaioannou, G. V., Yue, D. K., Triantafyllou, M. S., & Karniadakis, G. E. (2007). On the Effect of Spacing on the Vortex-Induced Vibrations of Two Tandem Cylinders. *Journal of Fluids and Structures*, 833-854.

[3] Prastianto, R. W., Otsuka, K., & Ikeda, Y. (2009). Vortex-induced Vibrations of a Flexible Free-hanging Circular Cantilever. *ITB J. Eng. Sci.*, Vol. 41, No. 2, 111-125.

[4] Prastianto, R. W., Otsuka, K., & Ikeda, Y. (2008). Dynamics of Two Flexible Hanging-off Cylinders in Staggered Configurations, *Proceedings of the Eighth (2008) ISOPE Pacific/Asia Offshore Mechanics Symposium*, Bangkok, Thailand, November 10-14, 2008.

[5] Prastianto, R. W., Otsuka, K., & Ikeda, Y. (2008). Experimental Study on Two Flexible Hanging-off Cylinders undergoing Wake Interference, OCEANS '08 MTS/IEEE Kobe-Techno_Ocean'08 – Voyage toward the Future OTO’08, Kobe, Japan, April 8-11, 2008.
[6] Prastianto, R. W., Otsuka, K., & Ikeda, Y. (2008). Hydrodynamic Forces on Multiple Hanging-off Circular Cylinders in Uniform Flows, 18th International Offshore and Polar Engineering Conference (ISOPE 2008), Vancouver-BC, Canada, July 6-11, 2008.

[7] Zdravkovich, M. M. (1981). Review and Classification of Various Aerodynamics and Hydrodynamics Means for Supressing Vortex Shedding. Journal of Wind Engineering and Industrial Aerodynamics, 145-189.

[8] Sugiwanto, A., Prastianto, R. W., Murdjito, Djatmiko, E. B. (2013). A numerical study on cylinders with passive control device of helical rods with gap for reducing vortex-induced vibration. International Conference on Sustainable Infrastructure and Built Environment (hal 357-368), Bandung.

[9] Prastianto, R. W., Musthofa A. Z., Arianti, E., Handayani, Murdjito, Suntoyo, and Fariduzzaman. (2014). Triple Helical Rods with Gap as Passive Control Device for Reducing Fluid Forces on A Cylinder. The 9th International Conference on Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia, MT-27, Oktober 24-25.

[10] Wieselsberger, C. (1922). New Data on the Laws of Fluid Resistance. T. N. No. 84, N. A. C. A.

[11] Kitagawa, T and Ohta, H. (2008). Numerical investigation on flow around circular cylinders in tandem arrangement at a subcritical Reynolds number. Journal of Fluids and Structures 24, 680-699.

[12] Prastianto, R. W., Syahroni, N., and Murdjito (2016). Kajian Evaluasi Kinerja Piranti Inovasi Baru Pereduksi Getaran akibat Vorteks pada Komponen Struktur Anjungan Lepas Pantai dalam Konfigurasi Jamak. Penelitian Unggulan Perguruan Tinggi (PUPT) – Tahun ke-2, LPPM - Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia (in Indonesia Language).