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The Effect of the Addition of Inlet Disturbance Body (IDB) to Flow Resistance Through the Square Cylinders Arranged in Tandem

Nasaruddin Salam, Rustan Tarakka, Jalaluddin, Reza Bachmid

Abstract – *Flow resistance through the square cylinders arranged in tandem, with the addition of Inlet Disturbance Body (IDB) in the form of circular cylinder, was analyzed by computational fluid dynamics (CFD) simulation using FLUENT 6.3.26 software as well as by experiments on resistance force and pressure distribution analysis. There were 5 (five) Reynolds numbers (Re_D) employed for the entire samples. Reynolds numbers were calculated based on condition of square cylinders arranged in tandem with diameter (D) of 70 mm. Re_D values gained range from 30,625 to 96,250. The ratios of diameter of IDB circular cylinder and diameter of square cylinder diameter (d/D) were varied in three (3) levels, d/D = 0.08; 0.14 and 0.20, while the ratios of the distance between the cylinders and square cylinder diameter (L/D) were varied in 8 (eight) levels of L/D = 0.0 to 1.0. The experimental results showed the pattern of the value of drag coefficient (C_D) and pressure coefficient (C_P) decreasing with an increase in L/D and d/D. Lowest values of C_D and C_P obtained were 1.67 and 0.87 respectively for L/D = 0.43 and d/D = 0.14 for all values of the Reynolds number. It was caused by flow separation absorbed by the addition of IDB circular cylinder prior to the square cylinder arranged in tandem. For the value of L/D larger or smaller than 0.43, the values of C_D and C_P escalate because the vortex flow was pushed upward the flow, hence causing the boundary layer on top of the square cylinder to increase. This phenomenon is validated with CFD simulation. Placement of a circular cylinder as IDB mounted prior to square cylinders arranged in tandem is resulting in the reduction of resistance of square cylinder from C_D = 2.13 to C_D= 1.67 or as many as 21.5962% and reduction of the pressure distribution of C_P = 1.02 to C_P = 0.87 or at 14.7059%. Based on these results, the optimal values of L/D and d/D due to the addition of IDB were L/D = 0.43 and d/D = 0.14 with values of C_D = 1.67 and C_P = 0.87.* ***Copyright © 2017 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Diameters Ratio d/D, Distance/Diameter Ratio L/D, IDB (Inlet Disturbance Body), Drag Coefficient C_D, Pressure Coefficient C_P, Reynolds Number Re_D*

Nomenclature

A	Area of square cylinder section
C_D	Drag coefficient
C_P	Pressure coefficient
D	Diameter of square cylinder
d	Diameter of circular cylinder
F_{dth}	Theoretical drag force
F_{dact}	Actual drag force
h	Circumferential tapping static head
h_m	Static head of manometer of air flow
L	Space between circular cylinder and square cylinder
P	Tandem space of square cylinders
Re	Reynolds number
U	Incoming air flow velocity to wind tunnel
ρ	Air density
υ	Air kinematic viscosity

I. Introduction

The flow through the square cylinders arranged in tandem is a form often used in structural and transportation engineering. Various applications of the square cylinders which are formed in certain arrangements such as inline, staggered or square arrays are applied in heat exchangers such as shell-and tube or tube banks, as well as in cooling towers, chimneys, the supporting structures of offshore platforms and ports, trains, boat trailers (barges) and trailers [1]-[25]. Wind and water loads on a structure are some of the main factors that have to be considered in the design. It is known that the load of wind and water on a structure in groups has different characteristics on a single structure with the same shape, because combined interference from the flow around the structure in groups showed a variety of interesting and unpredictable phenomena. Efforts to reduce drag force have been conducted by many researchers. Some show how to reduce the drag force on a single cylinder or arranged in tandem with a variety of methods.

Research on the reduction of drag force using disturbance body has been widely applied. According to Alam, et al. [1], when the circular cylinder arranged in

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tandem wherein in front of both cylinders is given a T-shaped disturbance plate, with head width of 5 mm and the distance to the cylinder is varied to obtain the optimum position, the optimal results obtained when variations of the distance of cylinders to the diameter of cylinders were at L/D = 1.0 to 1.5. Lee et al [2] examined the influence of small control rod mounted on the upstream of the cylinder with focus to the drag characteristics and flow structures. The Reynolds number based on the size of the diameter of the main cylinder (30 mm) was about Re = 20,000. The maximum reduction of the total drag coefficient of the entire system including the main cylinder and control rod was about 25%. In addition, Alam also did research by varying the values of L/D and d/D which resulted in the decrease of the total drag coefficient of the system. From this study, it was found that the ideal diameter ratios of small control rod as disturbance are $d/D = 0.233$ and L/D = 2.0 up to2.08 as the ideal distance of small control rod laying positions.

Tsutsui and Igarashi [3] examined the reduction of drag on the circular cylinder air flow. In their study, they mounted the disturbance rod on the upstream cylinder. From this study, it was found that the flow pattern will change depending on the diameter of the disturbance, the distance and the Reynolds number. The diameter of cylinder specimen was 40 mm, and diameters of trunk ranged from 1 to 10 mm. The Reynolds number was based on the diameter of the cylinder from 1.5×10^4 to 6.2×10^4. Reduction of the total drag which includes drag of the rod was 63% compared to that of the cylinder.

The characteristics of fluid flow through the triangular cylinders and square cylinders were investigated by Salam et al [4] using computational fluid dynamics (CFD) with program FLUENT 6.3.26 and later validated with photos of flow visualization. The study took place in a laminar flow area with Reynolds number of $Re_D = 8{,}52\times10^4$ at great speed (free) U = 8 m/s. In this study, ratios of the space of cylinders to the diameter of square cylinder (L/D) were varied, namely 0.0; 1.0; 2.0; 3.0; 4.0 and 5.0, while the ratio of the diameter of the circular cylinders to the diameter square cylinders (d/D) was constant at 0.5. The result of this research was the placement of a triangle in front of the cylinder square cylinder resulting in lowering barriers on the square cylinder with a reduced biggest obstacle occurs at L/D = 1.0.

According to Etminan et al [5], characteristics of aerodynamic flow as a result of the interaction of two square cylinders mounted in tandem in laminar flow (low Reynolds number) were that vortex flow is influenced by the magnitude of the Reynolds number, while the action of force differ from the upstream cylinder and the downstream cylinder, resulting the difference in drag coefficient value characteristics. Relations of tandem circular cylinder with square cylinders in wind tunnels with height H was examined by Daloglu [6] which were placed upstream in turn. The distance between the cylinders was varied with the ratio of S/d ranged from 0 to 10. The results of this study showed that the characteristics of the decreasing pressure is influenced by the ratio of the diameter of the cylinders and cylinder spacing ratio with the diameter of circular cylinder (S/d). Interesting fact from the acquired characteristics is that at S/d = 2 the smallest value of the pressure decrease occurred for all treatments of diameter variations, the positions and the Reynolds numbers.

Hasabe et al [7] conducted research on two square cylinders mounted tandem with variations in L/D from 2 to 5, installing pressure taps on half of the circumference of each cylinder. The results of this study showed that the average pressure distribution coefficient at each tap position is different for any change in L/D. The average pressure distribution coefficient was negativeon the top and back of each cylinder, which indicates that separation occurs on that part. The smallest value was obtained at L/D = 4 and the position of GH taps or the rear cylinder into two, which was around -1.6.

Lankadasu and Vengadesan [8] examined the influence of the interference of two square cylinders mounted in tandem. The treatments were by changing the ratio of the second cylinder spacing (L) with the width of the cylinder (d) or by changing the amount of L/d from 2 to 7 and dimensionless parameter for sliding (K) from 0.0 to 4 of the fixed Reynolds number (Re) of 100. The results of this study indicated that the parameters K and L/d tremendously influence on the magnitude of Strouhal number (St).

Karthik and Kumaraswamidhas [9] investigated fluid flow characteristics through square cylinders with different ratio of space by two dimensional computational simulations performed on a range of transverse gap ratios ($1.0\leq T/D\leq4$) between the cylinders arranged in side by side configuration using the lattice-Boltzmann method (LBM) with respect to Bhatnagar-Gross-Krook (BGK) collision model. Nabovati and Sousa [10] confirmed in fluid flow simulation in a 2D random arrangement of square obstacles with different aspect ratios. According to Wang and Tan [11], while the Reynolds number based on the cylinder diameter is fixed at $Re = 1.1\times10^4$, the center-to-center pitch ratio between adjacent cylinders was varied from P/D = 2.0 to 4.0.

Sumner et.al [12] found that if two circular cylinders arranged in tandem underwent changes on ratio of space and diameter of cylinders (P/D) from 1.0 to 5.0 and changes of axial angle of both cylinders (α) from 0° to 90° with laminar air flow with Re = 850 to Re = 1900 flow characteristics will be shear layer, with changes of flow separation and vortex. A two-dimensional numerical simulation of flow around four cylinders in an in-line rectangular configuration was studied by using the lattice Boltzmann method (LBM) with special attention to the effect of the spacing between the cylinders. With Reynolds number Re= 100 and the spacing ratios L/D were set at 0.5, 1.5, 2.5, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0 and 10.0, four different features were shown depending on the spacing (single square cylinder, stable shielding flow, wiggling shielding flow and a vortex shedding flow), Islam, et.al., [13]. Nidhul et.al [14] found that the flow induced force and Strouhal number for the flow around

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square cylinder were greatly dependent on the position of the flat plate. As gap distance increases, the drag force and Strouhal number decreases and reaches a minimum value at gap distance G=2.5D. Beyond this critical gap distance, both Strouhal number and Fd increases. Ozgoren and Dogan [15] investigated flow structures on downstream of the sharp-edged single and two and three side-by-side square cylinders (SCs) immersed in a uniform open channel water flow were studied by a technique of particle image velocimetry (PIV). Experimental results of wake flow structures were presented for gap ratios (G/D) in the range of $1.0 \leq G/D \leq 3.0$ for Reynolds number values of 1050, 2450 and 3400. The flow behind two side-by-side circular cylinders was also experimentally investigated by Wang and Zhou [16] based on laser-illuminated flow-visualization, particle image velocimetry and hotwire measurements. The flow was classified as three regimes: single street (the cylinder center-to-center spacing $T/d < 1.2$), asymmetrical flow ($1.2 < T/d < 2.0$) and two coupled street ($T/d > 2.0$).

Shyam Kumar and Vengadesan [17] investigated the effect of transverse gap ratio on the flow characteristics past two Equal Sized Square Cylinders (ESSC) in side-by-side arrangement at Re = 50,000 using Large Eddy Simulation (LES). The Lower Square Cylinder (LSC) has a higher lift coefficient for all gap ratios, except for T/D = 1.75.

Patil and Lakshmisha [18] used quadratic least squares (QLS) procedure to extract the first-order derivatives of distribution functions up to the second-order accuracy. The numerical results showed better agreement with the previous findings for a flow through a single circular cylinder. Igarashi and Shiba [19] found the for the D-shape and an I-shape cylinders with a cutting angle of 50-53° and for Reynolds number $Re > 2.3\times10^4$, the shear layer separated from the front edge reattaches on the circular arc of the cylinder, and a transition in the boundary layer as well as turbulent separation occur, the wake width decreases and the vortex formation region goes downstream. The Strouhal number increases beyond 0.28, the base pressure coefficient rises, and the drag coefficient of the cylinders decreases to half the value for circular cylinders.

For a wavy square cylinder (L/D=1), significant mean drag coefficient reduction and fluctuating lift suppression were obtained for the Reynolds numbers of 100, 500 and 5000 compared with that of the plain straight square cylinder at the same flow conditions, Lam et.al. [20]. Rowghani et.al [21] investigated the 2D low past a square cylinder inside a channel (B = 1/8) for the Reynolds number range $0.5 \leq Re \leq 300$ using lattice Boltzmann method (LBM).

Based on the theory and research results mentioned above, reduction of the coefficient of resistance of an object or a circular cylinder and square cylinder can be obtained by arranging them in tandem or by mounting the disturbing cylinder in front of the cylinder with a circular cylinder, square cylinder or cylinders triangle, and by changing the distance and diameter (the interaction between the cylinders). The question is whether the coefficient of resistance will decrease if the circular cylinder as a disturbing (IDB) is mounted in front of square cylinders arranged in tandem. The next question is what will be the magnitude of the reduction of resistance of square cylinders if arranged in tandem and disturbed by a circular cylinder. In connection with this, it was then analyzed the effect of adding inlet disturbance body (IDB) to the flow resistance through the square cylinders arranged in tandem. The solution of this problem is as much as possible to reduce complexities, especially in estimating the relationship between the coefficient of resistance and the boundary layer and the flow separation that could occur in tandem arranged objects with additional inlet disturbance body (IDB).

II. Methodology

The first stage of this research was began with CFD numerical simulation based on Finite Volume Method, that used Gambit 2.4 as grid generator and Fluent 6.3.26 as solver and post processing. Viscous model of laminar was used in this study. Meshing types of quad/tri element with pave were used in the numerical simulation. The selection of meshing type was done with consideration to obtain accurate results, where the domain of computational model of 2D-shaped was split into discretization division and expected to yield accurate results. Details of computational conditions are given in Table I.

TABLE I
COMPUTATIONAL CONDITION (THE MODEL IS 2D, STEADY STATE)

Fluid (air) properties	Density	1.186 kg/m³
	Viscosity	0.000018348 kg/ms
Boundary condition without IDB	Test model	Wall
	Pressure outlet	Pressure outlet
	Velocity inlet	Velocity inlet
	Wall	Wall
Boundary condition with IDB	Test model	Wall
	Pressure outlet	Pressure outlet
	Velocity inlet	Velocity inlet
	Wall	Wall
Upstream velocity		11 m/s

The final stage of this study was carried out using experimental approach. Collection of data was conducted in Fluid Mechanics Laboratory Department of Mechanical Engineering, Faculty of Engineering, Hasanuddin University, which was performed on the sub-sonic wind tunnel facility. Furthermore, experiment of resistance force and the distribution of pressure across the flow of the test object were conducted. Then, the spacing of square cylinders arranged in tandem or cylinder (1) and cylinder (2) was made constant. It was then treated with five (5) levels of air flow rate and 8 (eight) ratio of the distance between cylinder IDB with cylinder square (L/D) and three (3) levels of ratios in diameter between the cylinder IDB with cylinder square (d/D).

The cylinder square test object were made in two (2) pieces of the same width, height and the length (D) of 70 mm, while the cylinder IDB in the form of a circular

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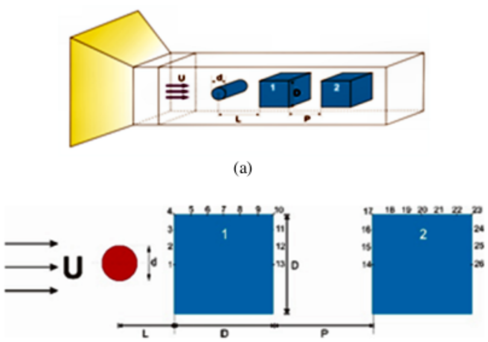
cylinder were made in 3 (three) pieces with different diameter (d) of 5.6 mm; 9.8 mm and 14 mm. The material used in the manufacture of the test object is acrylic with a thickness of 2 mm. Figures 1 below show the position of cylinder IDB (L) with a length or diameter of the square cylinders arranged in tandem (D), where the diameter of first square cylinder (1) is similar to that of second square cylinder (2). Additional circular cylinder IDB is mounted on the front, with size made smaller than that of the square cylinder. Figure 1(a) shows the placement of the specimen on a test section of wind tunnels for data retrieval of resistance force, while the Figure 1(b) shows the wind tunnels for data retrieval of flow visualization.



(a)

(b)

Figs. 1. The addition of inlet disturbance body (IDB) on a circular cylinder square cylinders arranged tandem. (a) The position of the specimen in wind tunnels and (b) placement position pressure tap

The wind tunnel used is that with low speed (low-speed wind tunnel) made by Plint & Partners Ltd. Engineers [22], where the speed of the airflow which flow through the test section size of 300 mm × 300 mm is maximum of 25 m/s.

To analyze experimental data from observation resistance force and the distribution of pressure, or to determine the flow characteristics in the form of C_D, C_P, F_{dth} and Re, as a result of extra IDB on the square cylinders arranged in tandem, the following equation were used. Equation (1) is used to determine drag coefficient C_D where, actual or measured resistance force (F_{dact}) and theoretical resistance force or air flow (F_{dth}), obtained from equation (2). To determine the Reynolds number, equation (3) is used, where U is the flow rate across the tested specimen and D is the diameter of the square cylinder which is the length of its sides. In determining the pressure coefficient, equation (4) is used, where the variable of static head of manometer of air flow before crossing the specimen (h_{sm}), static head at every tapping point along surface of the specimen (h), and the total head of Pitot tube manometer of air flow before crossing specimen (h_{tm}):

$$C_D = \frac{F_{d_{act}}}{F_{d_{th}}} \tag{1}$$

$$F_{d_{th}} = \frac{1}{2}\rho U^2 A \tag{2}$$

$$R_e = \frac{UD}{\upsilon} \tag{3}$$

$$C_P = \frac{h_{sm} - h}{h_{sm} - h_{tm}} \tag{4}$$

The study took place in a laminar flow area that is within Reynolds number calculated based on square cylinder diameter of Re_D = 30 625; 48 125; 65 625; 78 750 and 96 250 or the incoming air flow velocity to wind tunnel (U) = (7; 11; 15; 18 and 22) m/s. Ratios of distance of IDB cylinder with diameter square cylinder arranged in tandem (L/D) were varied in 0,00 (without IDB); 0.14; 0.29; 0.43; 0.57; 0.71; 0.86 and 1.00, while the ratio of the diameter of the IDB cylinder to square cylinder (d/D) were 0.08; 0.14 and 0.20.

III. Results and Discussion

The results of numerical simulation of contours of pressure, contours of velocity magnitude, contours of stream function and contours of vorticity with the variation of L/D with velocity U = 11 m/s with or without the addition of additional IDB are shown in Figures 2. Figure 2(a) shows an increase in pressure on the front side of the cylinder 1, which then decreases dramatically at the top, bottom and rear cylinder 1, while the pressure on cylinder 2 tends to be stable. In Figure 2(b), flow separation results on boundary layer to be pushed upward therefore the boundary layer thickness increases, both on the cylinder 1 and cylinder 2. In addition, it also results in the expansion of vortex behind the cylinder 2 which is very large, as shown in Figure 2(c). In Figure 2(d), it is shown that the vortex started from the front side of cylinder 1 to cylinder 2.

Figures 3 and Figures 4 show the effect of adding inlet disturbance body (IDB) in the same velocity or Reynolds number (U = 11 m/s or Re_D = 48,125) against no IDB. Addition of IDB with the same d/D of 0.14 with different L/D is shown in Figure 3 (L/D = 0.43), whereas L/D = 1.00 is shown in Figure 4. Both figures show pressure drop, flow separation, thick boundary layer and vortices, compared to that with no IDB. This emphasizes the effect of adding to the IDB to flow characteristics through the square cylinders arranged in tandem.

The results of the experiment in form of measurements of the pressure distribution and pressure coefficient analysis around square cylinder 1 and square cylinder 2 indicate that the location or position of pressure tap with the occurrence of flow separation, as shown in Figures 5 through Figure 11.

Furthermore, Table II shows the value of pressure coefficient (Cp) on the front side of the square cylinders 1 and 2, both without cylinder disturbance (L/D = 0.00) and with a disturbance cylinder with L/D = 0.14; 0.43 and 1.00, at the same Reynolds number Re = 96250.

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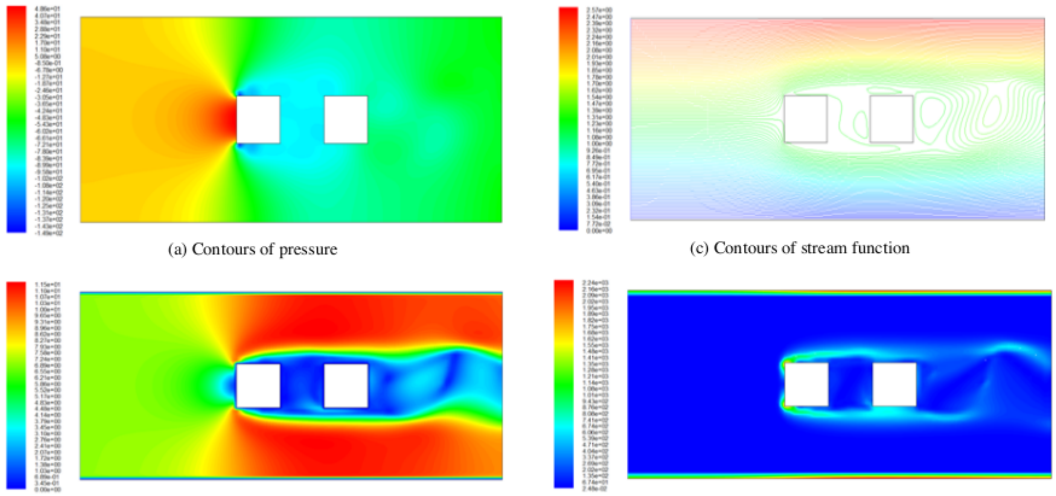


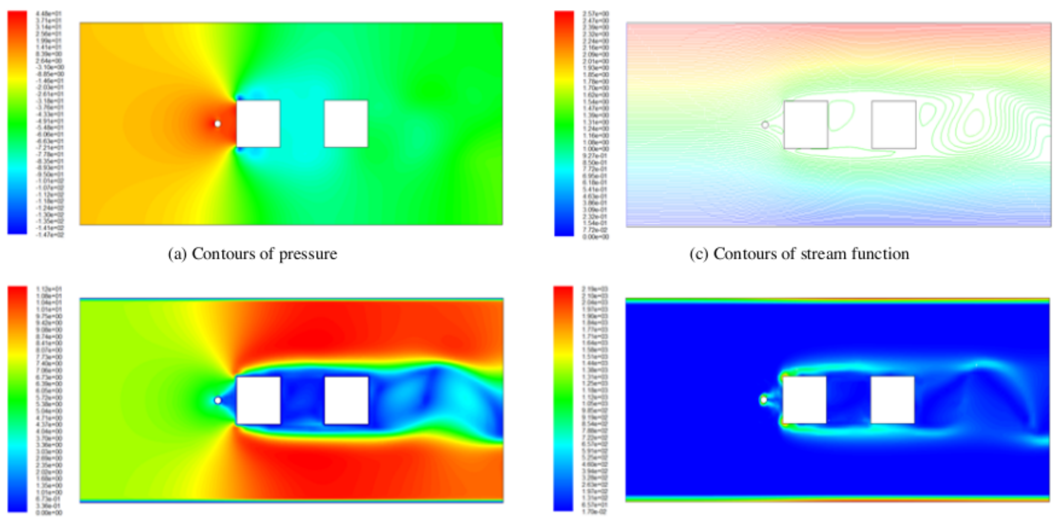
(a) Contours of pressure

(c) Contours of stream function

(b) Contours of velocity magnitude

(d) Contours of vorticity

Figs. 2. Simulation CFD at U = 11 m /s (Re_D = 48125) and without IDB



(a) Contours of pressure

(c) Contours of stream function

(b) Contours of velocity magnitude

(d) Contours of vorticity

Figs. 3. Simulation CFD at U = 11 m /s (Re_D = 48125); d/D = 0.14 and L/D = 0.43

Based on the values in Table II, the smallest value of the coefficient is occurred in the addition of IDB with d/D = 0.43 and L/D = 0.43, i.e. C_P = 0.87 on a square cylinder 1 (S1) and C_P = 0.05 in the square cylinder 2 (S2), with decreasing value of C_P compared to set without IDB mounted with ratio of up to 14.7059%.

The experiment results on resistance force obtained flow drag coefficient (C_D) at L/D = 0.00 (without IDB); 0.14; 0.29; 0.43; 0.57; 0.71; 0.86 and 1.00, and d/D = 0.08; 0.14 and 0.20 to the treatment of five (5) levels of with the same air velocity (U) 7 m/s to 22 m/s or the Reynolds number Re_D= 30625 up to 96250.

From Table III, the smallest value of C_D was 1.67 at d/D = 0.14 and L/D = 0.43. When this value is compared with a disturbance without cylinder (L/D = 0.00) with the value of C_D is at 2.13, the use of circular cylinder disturbance (IDB) could reduce the resistance to 21.5962%.

Furthermore, the graph below shows the relationship between C_D with Re on several constant levels of L/D (Figures 12) and the relationship of C_D with L/D at several constant levels of Re (Figure 13) as well as the relationship between C_D with L/D at several constant levels of d/D (Figure 14).

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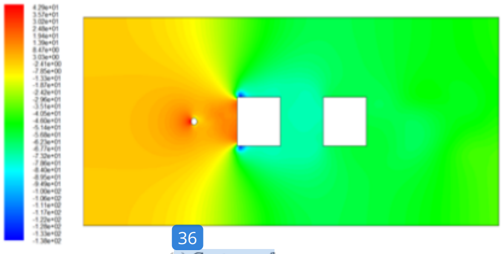
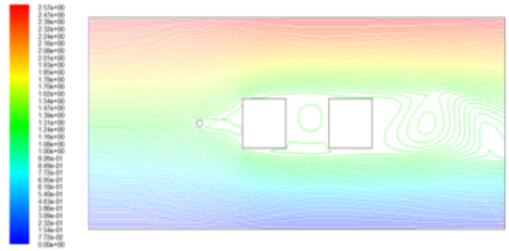
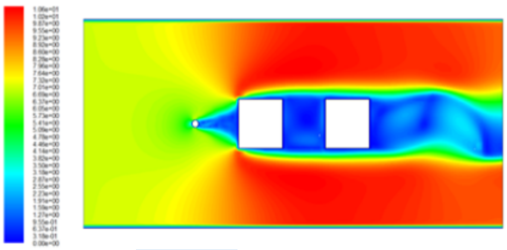


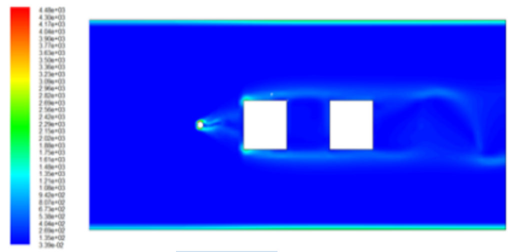
(a) Contours of pressure



(c) Contours of stream function

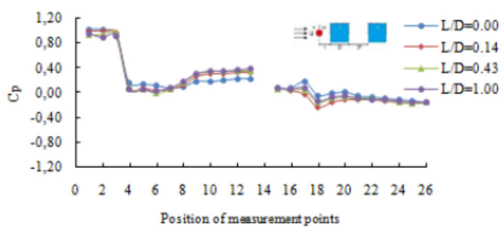


(b) Contours of velocity magnitude

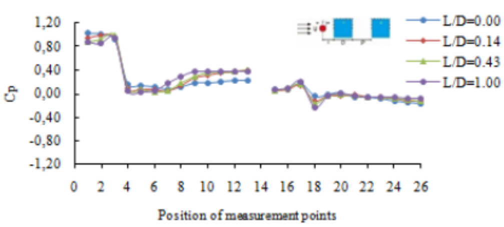


(d) Contours of vorticity

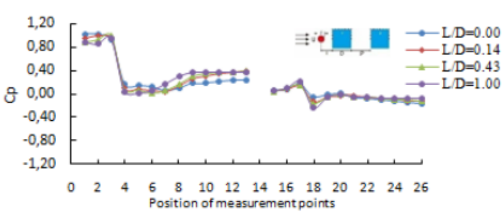
Figs. 4. CFD simulation at U = 11 m/s (Re_D = 48125); d/D = 0.14 and L/D = 1.00



(a) d/D = 0.08



(b) d/D = 0.14



(c) d/D = 0.20

Figs. 5. The relationships between pressure coefficient (Cp) and the position of measurement points at Re_D= 65625

TABLE II
COEFFICIENT OF PRESSURE (C_p) OF SQUARE CYLINDERS ARRANGED IN TANDEM WITH THE ADDITION OF INLET DISTURBANCE BODY (IDB) IN THE MEASUREMENT POSITION POINT 1 ON THE CYLINDER 1 (S1) AND THE MEASUREMENT POSITION POINT 14 ON THE CYLINDER 2 (S2), THE REYNOLDS NUMBER IS CONSTANT AT Re = 96250

d/D	L/D = 0.00 (Without IDB)		L/D = 0.14		L/D = 0.43		L/D = 1.00	
	S1	S2	S1	S2	S1	S2	S1	S2
0.08	1.02	0.07	0.99	0.07	0.93	0.06	0.94	0.08
0.14	1.02	0.07	0.94	0.06	0.87	0.05	0.89	0.07
0.20	1.02	0.07	0.91	0.06	0.82	0.05	0.83	0.07

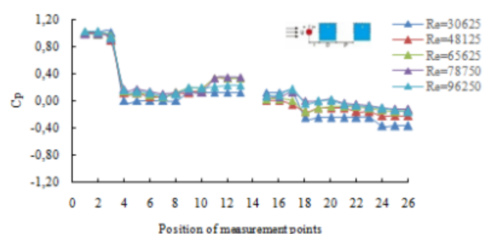


Fig. 6. The relationship between the pressure coefficient (C_P) to the position of measurement points with L/D =0.0 (without IDB) and d/D=0.14

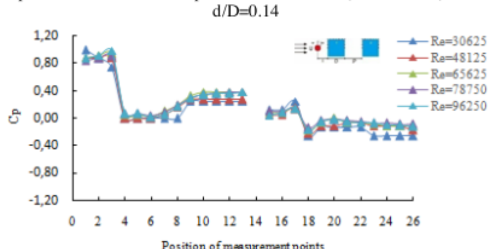


Fig. 7. The relationship between the pressure coefficient (C_P) to the position of measurement points with L/D = 0.43 and d/D = 0.14

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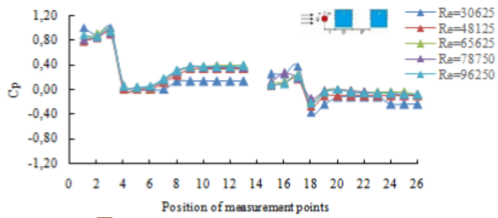


Fig. 8. The relationship between the pressure coefficient (C_P) to the position of measurement with L/D =1.00 and d/D=0.14

Fig. 9. The relationship between the pressure coefficient (C_P) to the position of measurement points with L/D =0.00 (tanpa IDB) and Re_D = 65625

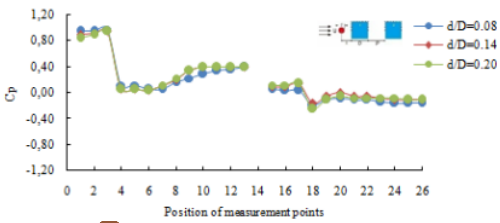


Fig. 10. The relationship between the pressure coefficient (C_P) to the position of measurement points with L/D =0.43 and Re_D = 65625

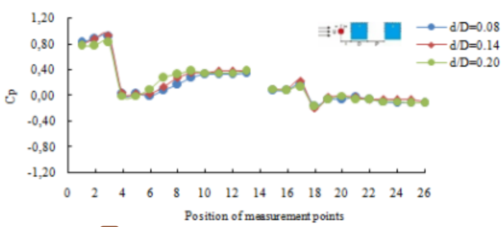
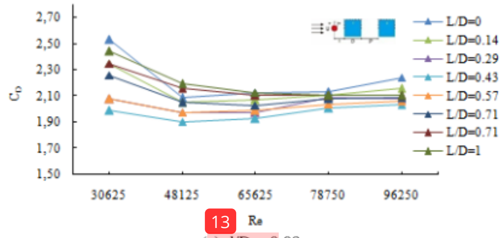


Fig. 11. The relationship between the pressure coefficient (C_P) to the position of measurement points with L/D = 1.00 and Re_D =65625

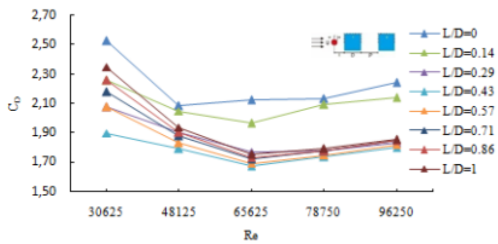
The pattern of characteristics shown in Figures 12 (a), (b) and (c) shows that the changes of *d/D* do not affect the characteristic pattern C_D of the Re_D, in regard that if Re_D is enlarged, the value of C_D is getting smaller. When compared to the same Re_D, the value C_D of *d/D* = 0.08 is greater than the *d/D* = 0.14, as well as for *d/D* = 0.20. smallest values C_D obtained on *L/D* ratio of 0.43 for all levels of *d/D* and Re_D. This shows that at *L/D* = 0.43, separation of flow and flow vortex in front of the square cylinder is the smallest, so that the smallest growth boundary layer is obtained, as shown in CFD simulation in Figures 3 and 4.

TABLE III
DRAG COEFFICIENT (C_D) SQUARE CYLINDERS ARRANGED IN TANDEM WITH THE ADDITION OF INLET DISTURBANCE BODY (IDB) ON THE SAME REYNOLDS NUMBER OF Re_D = 65625 WITH VARIATION OF D/D AND L/D

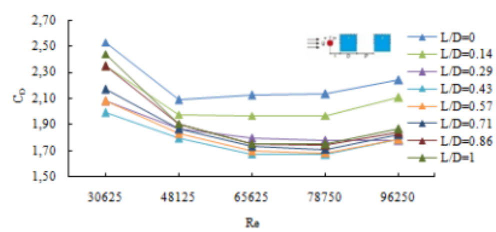
d/D	L/D=0.00	L/D=0.14	L/D=0.43	L/D=1.00
0.08	2.13	2.07	1.93	2.13
0.14	2.13	1.97	1.67	1.75
0.20	2.13	1.97	1.69	1.75



(a) d/D = 0.08



(b) d/D = 0.14



(c) d/D = 0.20

Figs. 12. The relationship between Re and the drag coefficient (C_D) of square cylinders arranged in tandem and the addition of circular cylinder disturbance (IDB) at 8 level of L/D

The pattern of characteristics shown in Figures 13 (a), (b) and (c) indicates that the changes do not affect the Re characteristic pattern of C_D to *L/D*, that is, when *L/D* increased, then the value of C_D is getting smaller, until at *L/D* = 0.43, then C_D becomes greater when *L/D* enlarged to *L/D* = 1.0. It occurred also in every level of same *d/D* and Re_D. The smallest value of C_D = 1.67 is obtained at a ratio of *L/D* = 0.43 and *d/D* = 0.14 which is a turning point of C_D and is also an optimal value as well as a proof that the appropriate placement of circular cylinder disturbance (IDB) could reduce resistance. To further clarify why this could happen, it can be seen on CFD simulation in Figures 2, 3 and 4.

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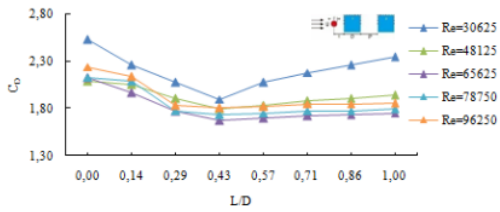
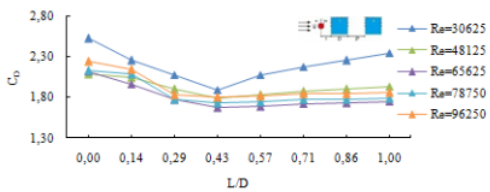
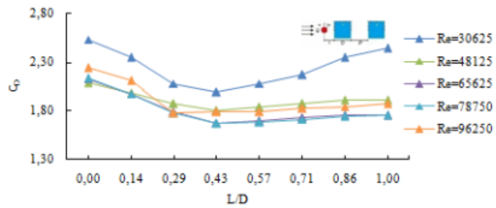


(a) d/D = 0.08



(b) d/D = 0.14



(c) d/D = 0.20

Figs. 12. The relationship between L/D with a drag coefficient (C_D) of square cylinders arranged in tandem with the addition circular cylinder disturbance (IDB) on 5 levels of Reynolds Numbers

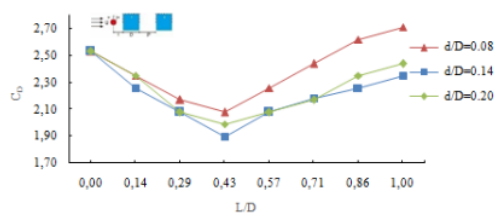


Fig. 13. The relationship between L/D and a drag coefficient (C_D) square cylinders arranged in tandem with the addition circular cylinder disturbance (IDB) Re = 30625 by 3 phase d/D.

Table IV shows the value of the drag coefficient on square cylinders arranged in tandem without disturbance cylinder, with the distance between the cylinders square, is equal to the diameter or length of side of square cylinders (D=70 mm) at five levels of flow rate flowing through the test specimen.

Based on the Figures 12 and 13 at the same Reynolds number (Re_D = 65625) with the addition of a disturbance cylinder (IDB) the smallest value of C_D obtained was 1.67 at d/D = 0.14 and L/D = 0.43. When compared to that without disturbance cylinder (as shown in Table IV), the C_D value obtained was 2.13 in Re_D = 65625. The ratio between two C_D values shows that the use of circular cylinder disturbance (IDB) reduce the resistance to 21.5962%.

TABLE IV
THE DRAG COEFFICIENT (C_D) WITHOUT DISTURBANCE CYLINDER AT VARIOUS LEVELS OF FLOW RATE THROUGH THE SQUARE CYLINDERS ARRANGED IN TANDEM

No	V (m/s)	F_{dact} (N)	F_{dth} (N)	C_D	Re
1	7	0.28	0.11	2.53	30625
2	11	0.57	0.27	2.09	48125
3	15	1.08	0.51	2.13	65625
4	18	1.56	0.73	2.13	78750
5	22	2.45	1.09	2.24	96250

IV. Conclusion

CFD numerical simulations and experiments on flow resistance through the square cylinders arranged in tandem with the addition of circular cylinder disturbance or inlet disturbance body (IDB) with L/D = 0.0 up to 1.0, and the velocity of inflow the wind tunnel or outflow on specimen of U = (7 to 22) m/s or a laminar flow at the Reynolds number Re_D = 30625 up to 96250, with variations of d/D = 0.08, 0.14 and 0.20 is summed up:

1. The larger the ratio of IDB distance to diameter of square cylinders arranged in tandem (L/D), the larger the drag coefficient, while L/D = 0.43 and d/D = 0.14 were the coefficient for the smallest resistance(C_D = 1.67).
2. The larger the value of the Reynolds number (Re_D) the smaller the value of the drag coefficient on any variation of L/D. However, at the same Re_D, the smallest drag coefficient value were at L/D = 0.43 and d/D = 0.14.
3. The pattern of reduction of drag coefficient (C_D) is approximately similar to each changes in the flow velocity or the Reynolds number and L/D and d/D ratio.
4. The pattern of the pressure distribution and pressure coefficients (C_P) is approximately similar to any changes in flow velocity or the Reynolds number and L/D and d/D ratio.
5. Change of characteristic in C_D and C_P indicates similar CFD simulation patterns. The addition of Inlet Disturbance Body (IDB) in front of the square cylinder arranged in tandem reduces the flow resistance for all level or change of the Reynolds number and L/D and d/D ratio.
6. Placement of a circular cylinder mounted IDB in front of square cylinder arranged in tandem is resulting in the reduction of resistance on square cylinder C_D = 2.13 to C_D = 1.67 or at 21.5962%, and the reduction of pressure distribution from C_P = 1.02 to C_P = 0.87 or at 14.7059%. Based on these results, the optimal value produced by the addition of IDB is at L/D = 0.43 and d/D = 0.14 with value C_D = 1.67 and C_P = 0.87.

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