A Study of the Drag Force of Flowing Water on Concrete Blocks: Predictive Approach of Concrete Blocks Ability to Resist Flood

Ali Hauashdh1*, Tan Lai Wai1, Junaidah Jailani1 and Ibrahim Alhawry1

1Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400, Batu Pahat, Johor, Malaysia.
*Corresponding author: gfl70112@siswa.uthm.edu.my

Abstract. The frequency of floods increases annually in many countries of the world due to climate change. Flood is typically coupled to flowing water moving faster than normal. Thus, understanding the drag force behaviour due to the flowing water on concrete blocks is essential to predict floods risks since the concrete is the predominant material used in the construction of buildings, bridges, dams, canals and other infrastructure over the world. Nonetheless, previous studies were mostly focused on the resistance of concrete structure due to the load force, and there is a lack of studies about the resistance of concrete structure due to the drag force of flowing water. Therefore, this study aims to estimate the drag force of flowing water, which causes the displacement of concrete blocks. Also, to investigate the effects of concrete mass and flow velocity on the drag force. Three concrete cubes were used with dimensions 0.15 m x 0.15 m x 0.15 m and weighing between 6.486 kg to 7.847 kg. The concrete cube is installed in the middle of the open channel 10-m long, 0.3 m wide and 0.46 m depth Armfield S6 MKII flume. In this study, the flowing water exerts force on the cube concrete block in the direction of flow, known as the drag force. It was observed the mass of the block is an essential factor that affects the drag force on a concrete cube due to flowing water. Therefore, each cube of concrete block with area 0.02235 (m2) and mass between 6.486 kg to 7.874 kg to be displaced was needed a drag force of flowing water between 2.737 N to 3.732 N. Also, it has been found that the drag force increases with the increasing the flow velocity.

1. Introduction
Climate change due to global warming increases the frequency of floods every year in many countries of the world [1]. Extreme climate variability has probably resulted in extreme climate conditions, including global warming increased precipitation which leads to higher intensity rainfall increases along the channels and rivers lead to floods which cause corrosion and damages to concrete infrastructure [2-4]. In fact, the consideration of flood risks within the design of the concrete structure, it is beneficial because it will help to manage the effects within the flood [5-7]. Therefore, the estimation of the drag force on the concrete blocks due to flowing water which has varied velocity, discharge and depth can predictive the concrete structure capability to resist flood.

The state of flow can be either in laminar, transitional, or turbulent [8]. The flow is laminar if the flow particles appear to move in definite smooth paths and the flow appears to be as a movement of thin layers on top of each other. In turbulent flow, the flow particles move in irregular paths that are not fixed in time or space. The relative magnitude of viscous and inertial forces determines whether the flow is laminar or turbulent [8].
Dutta et al. [9] have experimentally investigated the drag coefficient of flow past a square Plexiglas cylinder. They found that higher flow velocity increases the drag coefficient. In this study, the estimation of drag force required to move cubic concrete block is made and thus help researchers to relate the theoretical expression with the real flow situation. The drag force also is an essential parameter for civil engineers in the design of riverbank and shore protection systems. Therefore, this study aims to estimate the drag force that causes the displacement of concrete blocks due to flowing water. Also, to investigate how the mass of the concrete block and flow velocity affects the drag force of flowing water.

2. Methodology
The method of this study was done through an experimental laboratory approach. The main equipment and material used in this study are open channel flow Armfield S6 MKII flume and three different mass of cube concrete blocks. Three cubes of concrete having similar sizes and different mass were used in this study as shown in Figure 1. The three concrete cubes have labelled as cube A, B, and C, respectively. The concrete cube block is installed in the middle of the 10-m long, 0.3 m wide and 0.46 m depth Armfield S6 MKII flume, as indicated in Figure 2. The experiment of flow over each concrete cube is repeated three times to ensure consistency.

![Figure 1. Dimensions of the 3 concrete cubes investigated for the drag force of flowing water](image1)

![Figure 2. Open channel flow Armfield S6MKII glass-sided tilting flume](image2)

Table 1 shows the determination of flow states of open channel flow based on Froude number Fr and Reynolds number Re.
Table 1. States of flow in the open channel [8]

| States of flow           | Froude number Fr | Reynolds number Re |
|--------------------------|------------------|-------------------|
| Sub-critical laminar     | < 1.0            | ≤ 500             |
| Super-critical laminar   | > 1.0            | ≤ 500             |
| Sub-critical turbulent   | < 1.0            | > 12,500          |
| Super-critical turbulent | > 1.0            | > 12,500          |

According to Cengel et al. [10] and Yeh et al. [11], the drag force was calculated as given:

\[ F_D = \frac{1}{2} C_D A \rho V^2 \]  

\( F_D \) is the drag force, \( A \) = the area of the concrete cube facing the flow direction, \( \rho \) = density of water, and \( V \) = velocity of flow and \( C_D \) = The drag coefficient. \( C_D = 1.05 \) Cengel et al. [10].

3. Results and discussion

This section presents the results and discussion in four sub-sections, which are the flow state and the relationship between Reynolds number and discharge Q as well as Froude number and discharge Q, the estimation of drag force of flowing water, the effect of flow velocity on the drag force and the effect of concrete block mass on the drag force due to flowing water.

3.1. Flow state and relationship between Reynolds number, Froude number and discharge Q

The state of flow in the channel was determined based on Froude number and Reynolds number. Table 2 represents states of the flow based on Froude and Reynolds numbers at various discharges, depth flow and flow velocity along 10-m long and 0.3 m wide Armfield S6 MKII flume. The flow is transitional when \( 500 < Re \leq 12500 \) [8].

Table 2. States of flow based on Froude number and Reynolds number

| Q (m$^3$/s) | y (m) | V (m/s) | Fr  | Re       | State of flow     |
|------------|-------|---------|-----|----------|-------------------|
| 0          | 0     | 0       | -   | -        | -                 |
| 0.005      | 0.06233 | 0.2674 | 0.3419 | 11727.0 | Transitional      |
| 0.012      | 0.06333 | 0.6316 | 0.8013 | 28012.9 | Turbulent         |
| 0.014      | 0.06933 | 0.6731 | 0.8161 | 31787.7 | Turbulent         |
| 0.021      | 0.08500 | 0.8235 | 0.9019 | 44502.8 | Turbulent         |
| 0.025      | 0.09100 | 0.9158 | 0.9692 | 51660.6 | Turbulent         |
| 0.033      | 0.11500 | 0.9565 | 0.9006 | 62016.1 | Turbulent         |

Figure 3 the relationship between the Froude number and the discharge. It shows that the Froude number increases with increasing discharge. Meanwhile, Figure 4 shows the relationship between the Reynolds number and the discharge. It also shows that the Reynolds number increases with increasing discharge.
Figure 3. Froude number Fr increases with increasing discharge $Q$

Figure 4. Reynolds number Re is directly proportional to discharge $Q$

3.2. Estimation of drag force of flowing water

Table 3 explains three sets of experiments have conducted to observe the flow, which causes the concrete cube to start moving in the 0.3 m wide flume. The average velocity of flow ($V$) (m/s) and average drag force $F_D$ (N) were calculated as each experiment of flow over each concrete cube was repeated three times to ensure consistency. The velocity of flow observed in a 0.3 m wide flume, which causes concrete block A to be displaced, was 0.483 (m/s). While the velocity of flow observed in a 0.3 m wide flume, which causes concrete block B to be displaced was 0.532 (m/s). For block C velocity of flow observed in a 0.3 m wide flume, which causes concrete block C to be displaced is 0.564 (m/s). The velocity was inversely proportional to the flow cross-sectional area where the velocity increases with decreasing flow area and the discharge $Q$ is proportional with velocity. The flowing water exerts force on the cube concrete block in the direction of flow, known as the drag force. The drag force $F_D$ of flowing water that has displaced concrete block A was 2.737 N, drag force $F_D$ of flowing water that has displaced concrete block B was 3.320 and drag force $F_D$ of flowing water that has displaced concrete block C was 3.732 N.
Table 3. Drag shear force $F_D$ of flowing water on concrete blocks A, B, and C

| Concrete Block | Cube area ($m^2$) | Mass (kg) | Average Velocity of flow (m/s) | Average Drag force $F_D$ (N) |
|----------------|-------------------|-----------|------------------------------|-----------------------------|
| A              | 0.02235           | 6.486     | 0.483                        | 2.737                       |
| B              | 0.02235           | 7.582     | 0.532                        | 3.320                       |
| C              | 0.02235           | 7.847     | 0.564                        | 3.732                       |

3.3. Effect of velocity of flow on the drag force

Figure 5 shows the effect velocity of flow on the drag force due to flowing water. It is clearly observed that the drag force increases with increasing of the flow velocity. Drag force of flowing water on concrete block C was the highest at the same time with the highest velocity to displace concrete block C compared to drag force and velocity of flow for concrete block A and B. Therefore, drag force of flowing water on concrete blocks is directly proportional with a velocity of flowing water.

![Figure 5. Effect of velocity of flow on the drag force on concrete blocks](image)

3.4. Effect of concrete block mass on the drag force

Figure 6 shows the effect of cube concrete blocks masses on the drag force due to flowing water. Concrete block C is the heaviest with 7.847 kg, was needed to displace a drag force of flowing water equal to 3.732 N. Whereas, concrete blocks A is the lightest with 6.486 kg was needed to displace a drag force of flowing water equal to 2.737 N. Therefore, the drag force of flowing water that needed to move the concrete block is directly proportional to the mass of the concrete block. The effect of the drag force depends also on the orientation of the body that drag force will move it and its surface roughness [10].
4. Conclusion
In this study, the flowing water exerts force on the cube concrete block in the direction of flow, known as the drag force. This study has estimated the drag force of flowing water on concrete blocks that have displaced the concrete blocks. Also, this study has explained the effect of the velocity of flow and mass of concrete block to the drag force of flowing water. The drag force increases with the increasing velocity, which means that the force resisting the flow per unit area of the channel bed is proportional to the square of the velocity. The velocity is inversely proportional to the flow cross-sectional area where the velocity increases with decreasing flow area and the discharge Q is proportional with velocity. The mass of the block is an essential factor that affects the drag force on a concrete cube due to the flowing water. Thus, block C which has the highest mass equal to 7.847 kg was needed more flow force to move it from its place. Therefore, each cube of concrete block with area 0.02235 (m²) and mass between 6.486 kg to 7.847 kg to be displaced was needed a drag force of flowing water between 2.737 N to 3.732 N.

5. References
[1] Alfieri L, Burek P, Feyen L and Forzieri G 2015 Global warming increases the frequency of river floods in Europe Hydrol. Earth Syst. Sci. Discuss. 19 2247-2260
[2] Dore M H 2005 Climate change and changes in global precipitation patterns: what do we know? Environ. Int. 31 1167-1181.
[3] Jones P D and Hulme M 1996 Calculating regional climatic time series for temperature and precipitation: methods and illustrations Int. J. Climatol: J Royal Meteorol Soc. 16 361-377
[4] Saeidi A, Eslami E, Quirion M, and Seifaddini M 2019 Assessment of rock mass erosion in unlined spillways using developed vulnerability and fragility functions. Georisk: Assess. Manage Risk Eng. Syst Geohazards 1-13
[5] Bubeck P, Botzen W J and Aerts J C 2012 A review of risk perceptions and other factors that influence flood mitigation behavior Risk Anal: An Int. J. 32 1481-1495
[6] Pearson J, Punzo G, Mayfield M, Brighty G, Parsons A, Collins P and Tagg A 2018 Flood resilience: consolidating knowledge between and within critical infrastructure sectors. Environ. Syst. Decisions 38 318-329
[7] Wang X, Stewart M G and Nguyen M 2012 Impact of climate change on corrosion and damage to concrete infrastructure in Australia Climatic change 110 941-957
[8] Chow V T 1985 Open-channel hydraulics (New York: McGraw-Hill)
[9] Dutta S, Panigrahi P K and Muralidhar K 2008 Experimental investigation of flow past a square cylinder at an angle of incidence J. Eng. Mech. 134 788-803
[10] Cengel Y A, Turner R H, and Cimbala J M 2001 Fundamentals of thermal-fluid sciences (New York: McGraw-Hill)
[11] Yeh, H., Barbosa, A. R., Ko, H., & Cawley, J. G. 2014. Tsunami loadings on structures: Review and analysis Coastal Engineering Proceedings pp 1-13

Acknowledgments
The authors would like to express their sincere appreciation to the Faculty of Civil Engineering and Environmental, Universiti Tun Hussein Onn Malaysia for supporting this study.