The Impact of Vortex Formation Due to The Operational Dam Condition: A Review

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Abstract. There are various sources of energy throughout the world, renewable as well as non-renewable through which renewable energy sources are considered more environmentally friendly. Encompassed by all the sources of renewable energy, hydropower is considered the most beneficial source of energy. Proper operation of hydropower plant is very important for generating maximum energy by utilizing the available. However, formation of vortices at power intake can cause number of problems. The stronger vortices have more negative effects on the performance of hydropower plant which can also, draw debris and air into an intake causing vibration and damage to turbines. The present study addresses the vortices formation at the intake dam, several types of vortices and anti-vortex applications in order to overcome the vortex formations.

1. Introduction
Energy is very important for a developing country and the common energy used is electrical energy. There are various ways to harvest electricity energy by constructing power plant such as nuclear power plant, charcoal power plant, solar harvester, and hydropower. The role of hydropower has been changed from constant energy supplier to the highly flexible one to maintain the grid stability which leads to operate the hydropower under transient operations [1, 2]. Dam intakes divided into two types which are horizontal intakes and vertical intakes, that can be observed in Figure 1 while Table 1 summarize the study of vortex formation for two types of dam intake which horizontal and vertical.
Figure 1. Types of intake: (a) horizontal intake and (b) vertical intake.

Table 1. types of dam intake for vortex formation study

| Author                  | Types of intake study | Year |
|-------------------------|-----------------------|------|
| Padmanabhan and Hecker. [3] | Horizontal intake     | 1984 |
| Cheng and Ying. [4]     | Horizontal intake     | 2007 |
| Roshan et al. [5]       | Horizontal intake     | 2009 |
| Sarkardeh et al. [6]    | Horizontal intake     | 2010 |
| Kerem and Yildirim. [7] | Vertical intake       | 2010 |
| Trivellato. [8]         | Vertical intake       | 2010 |
| Amiri et al. [9]        | Horizontal intake     | 2011 |
| Wang et al. [10]        | Horizontal intake     | 2011 |
| Yang et al. [11]        | Vertical intake       | 2014 |
| Keller et al. [12]      | Horizontal intake     | 2014 |
| Taştan and Yıldırım. [13]| Vertical intake       | 2014 |
| Azarpira et al. [14]    | Horizontal intake     | 2014 |
| Sarkardeh et al. [15,16]| Horizontal intake     | 2014 |
| Suerich-Gulick et al. [17–19] | Horizontal intake   | 2014 |
| Sarkardeh. [20, 21]     | Horizontal intake     | 2017 |

Usually, horizontal intake was more preferred as compared to vertical intakes due to construction cost and fabrication materials [9]. In this review, the impact of vortex in the literature are reviewed with a focus on their formation in dam intakes and the anti-vortex applications in order to reduce the vortex formation.

2. The impact of vortex formation

In general, intake vortices can be recognized as a prevailing phenomenon which must be considered in hydraulic engineering applications and the formation of vortices leads to flow unsteadiness and non-uniformity at hydro machines [8, 9, 22]. Vortex formation at power intakes may occur at lower reservoir levels which can draw debris and air into an intake causing vibration and damage to turbines [6, 23–25]. Eventually, Yang et al., (2018) mentioned that the vortex strength increased accordingly, and the air-core diameter was around 3 – 4 m [26]. Instead, Zhang et al., (2018) stated that vortex is a typical flow structure in the hydro turbines [27], leading to various kinds of instabilities such as large pressure fluctuation [28, 29], significant noise, prominent vibrations, rotating stall [30], cavitation erosion [31], and material fatigue.
On the whole, Walker, (2016) discussed that there are no information was found on the loss of power generation with vortex suppressors, however many documents acknowledged that the design of a trash rack can create head loss which could reduce power generation of a turbine [32]. In other book section by Ratnayaka et al., (2009) mentions that, radial vanes are generally incorporated in the top of a bell mouth shaft to minimize the occurrence of vortex action, which can otherwise reduce the discharge capacity and cause problematic flow conditions in the shaft and tunnel [33].

In the past, study by Padmanabhan and Hecker, (1984) using horizontal intake approached to study the vortex formation with three types of condition: one pipe operation, two pipe operation and screen blockage test [3]. Based on findings, considerable swirl in the pipe flow was induced, and the swirl meter indicated higher swirl angles at lower submergences when the subsurface vortices were stronger [3]. In the book by Paul, (1998) stated that, for intakes feeding directly to a power tunnel, the exclusion of air is an important design consideration and the intake may require submergence to prevent vortex formation and air entrainment [34]. In contrast, findings by Azarpira et al., (2014) found that, velocity measurements in the reservoir showed that increasing the submerged depth from 1.6 to 3.2 has effect on reducing plane velocities, whereby the maximum plane velocity decreased about 30% [14].

Meanwhile, the study by Khanarmuei et al., (2018) encountered the strength of vortices that form in single and dual pipe intakes decreases by changing the intake direction from vertical to 45° and horizontal [35]. Based on their findings, the circulation number of vortices that formed at horizontal single and dual pipe intakes as compared to vertical single and dual pipe intakes was decreased on average 31% and 35%, respectively. In addition, the critical submergence was considerably affected by changing the intake direction at single and dual pipe intakes, and by changing the angle of pipe intakes from vertical to horizontal, the critical submergence at single and dual pipe intakes decreases 16% to 30% and 19% to 40%, respectively [35].

3. Vortex classifications
Alden Research Laboratory [36] classified vortices into 6 types of classification as shown in Figure 2(a) as compared to Sarkadesh et al., (2010) which classified the vortex formation into three class vortex which vortex class A, B and C in Figure 2(b). The vortices of class C are considered to be safe while Class B surface vortices are stronger and the rotation in the water surface extends down to the intake [6]. Lastly, the strongest vortices which should be avoided are categorised in class A which is in this class, air bubbles are trapped and conveyed down from the water surface to the intake.
4. Anti-vortex applications

Roshan et al., (2009) found that the vortices can be reduced by introduced anti-vortex walls (Figure 4) whereby anti-vortex wall was then recommended as a cheap method to prevent vortex formation in the prototype [5]. Based on their results of experiments, the type of vortices reduced from type 4 to type 2 and 1. Similarly, Sarkardeh et al., (2010) also proposed an anti-vortex which trash rack to reduce the vortices formation [6]. However, since water level in a reservoir should not be reduced to levels below the critical submergence, the volume of water in this zone cannot be used for power generation [9]. Thus, increasing the submergence of the intake to prevent the formation of air-entraining vortices may not always be an economical solution and be cost prohibitive.

5. Conclusions

Hydropower plant is the most energy harvester used throughout world due to higher energy output as well as renewable energy compared to other types of power plant. Consequently, formation of vortex at dam intake reduce the productivity of the collected electrical energy. The present study has been undertaken to review the earlier research work carried out in the area of dam intakes which the occurrence of vortex formation. It has been found that the water depth, $S$ affect the vortex formation at dam intakes and increasing the submergence of the intake will be cost prohibitive which
not always be an economical solution. In the current status, the impact of vortex reduces the turbine capabilities in generating electricity due to the air-entrain which lower the mass flow and increase void inside the penstock. Based on the review, anti-vortex can reduce the vortex formation but there are limited studies of the design for the anti-vortex. Thus, more studies for the design of anti-vortex are needed to optimally reduce the vortex formation.

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