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A siphon well model for hydraulic performance optimization and bubble elimination

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HIGHLIGHTS

- A new method was proposed to improve the hydraulic performance and bubble elimination.
- The diversion pier and diversion grid were used to stabilize the flow pattern.
- Double multi-hole orifices were arranged after the weir.
- The new method has a simpler construction and greater bubble elimination.

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ABSTRACT

In coastal nuclear power plants, bubble entrainment at the hydraulic jump in the siphon well causes foam pollution and salt fog erosion near the outfall of the siphon well. Thus, bubble elimination in siphon wells has been a topic of considerable interest. This study presents a new hydraulic performance optimization and bubble elimination method based on model experiments. Compared to previous methods, the new method has a simple structure, is effective in eliminating bubbles and is well adapted to different tide levels. The method mainly uses a diversion pier, diversion grid and multi-hole orifices to improve the hydraulic performance, thus reducing bubble entrainment at the hydraulic jump and shortening the bubble movement length in the siphon well. This study provides a valuable reference for the future siphon well design of coastal power plants.

1. Introduction

Coastal nuclear power plants are generally equipped with siphon wells to reduce pump head and save energy. A weir with a top elevation higher than the mean tide level is needed in the siphon well to avoid the influences of a changing tide level. Under low tide levels, water flows over the weir and forms a hydraulic jump, leading to foam pollution and harmful salt fog near the outfall of the siphon well.

A chemical defoamer is widely used to prevent foam pollution and salt fog. Chemical defoamers are effective but extremely expensive. For example, for the Dayawan nuclear power plant (installed capacity of 2×900 MW and circulating cooling water discharge of approximately 90 m^3/s) in China, the defoamer cost is approximately 5 million yuan (RMB) annually. For the Taishan nuclear power plant in China, the defoamer cost is at least 2 million yuan (RMB) annually (He and Yang, 2008; Long, 2004). Thus, using a chemical defoamer continuously during the lifetime of a power plant is extremely expensive. Moreover, the chemical defoamer is also a chemical pollutant that can cause secondary pollution of seawater and affect the ecological environment near the outfall of the siphon well.

Bubble entrainment at the hydraulic jump in the siphon well is the main reason for foam pollution. Hence, an alternative method for defoaming is to eliminate bubbles at the hydraulic jump to prevent the bubbles from entering the downstream outlet culvert. Researchers have considered several shapes for avoiding bubble entrainment, such as stratified diversion culverts, positive and negative plates, and so on. Upper shapes can partially solve the problems of bubble entrainment at the hydraulic jump but have complex structures, which are difficult to adapt to changing tide levels and decrease the discharge capacity of the siphon well (Ji and Qin, 2015; Zeng, 2009; Zhao et al., 2013).

Here, an experimental study is conducted for a coastal power plant and a new hydraulic performance optimization and bubble elimination method for the siphon well is presented. The method includes a diversion pier, diversion grid and multi-hole orifice.

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Compared to previous bubble elimination methods, the new method has a simpler construction, lower construction quantity, and greater bubble elimination and tide level adaption.

2. Project profile and experiment setup

2.1. Project profile

A detailed design of the siphon well model is shown in Fig. 1. The siphon well model is 2.4 m long and 3.6 m wide. The upstream inlet is a circular pipe with a diameter of 0.4 m, and the downstream outlet is a rectangular culvert with a length of 0.42 m. And Q is flow discharge, H is water depth after the weir. The siphon well model has two flow discharge conditions: winter discharge (Q = 156 L/s) and summer discharge (Q = 256 L/s). Each discharge has three water depth conditions, which are shown in Fig. 1b. A hydraulic jump forms when the water depth after the weir is lower than the height of the weir.

2.2. Experiment setup

A true dynamic similarity of aerated flows requires identical Froude, Reynolds and Weber numbers to be achieved in the prototype and model. Thus, a true dynamic similitude of flow aeration exists only at full-scale. In recent years, researchers have studied the mechanism of self-aeration in open channels as a function of bubble size, air concentration, Froude number, and Reynolds number, among other variables. Because of the complexity of air aeration at the hydraulic jump, the relationship between the scale model and prototype is still not fully understood (Chachereau and Chanson, 2011; Chanson, 2006). For flow aeration models, two approaches are generally recognized for combining the Froude similitude with a reasonable approximation of the rate of air

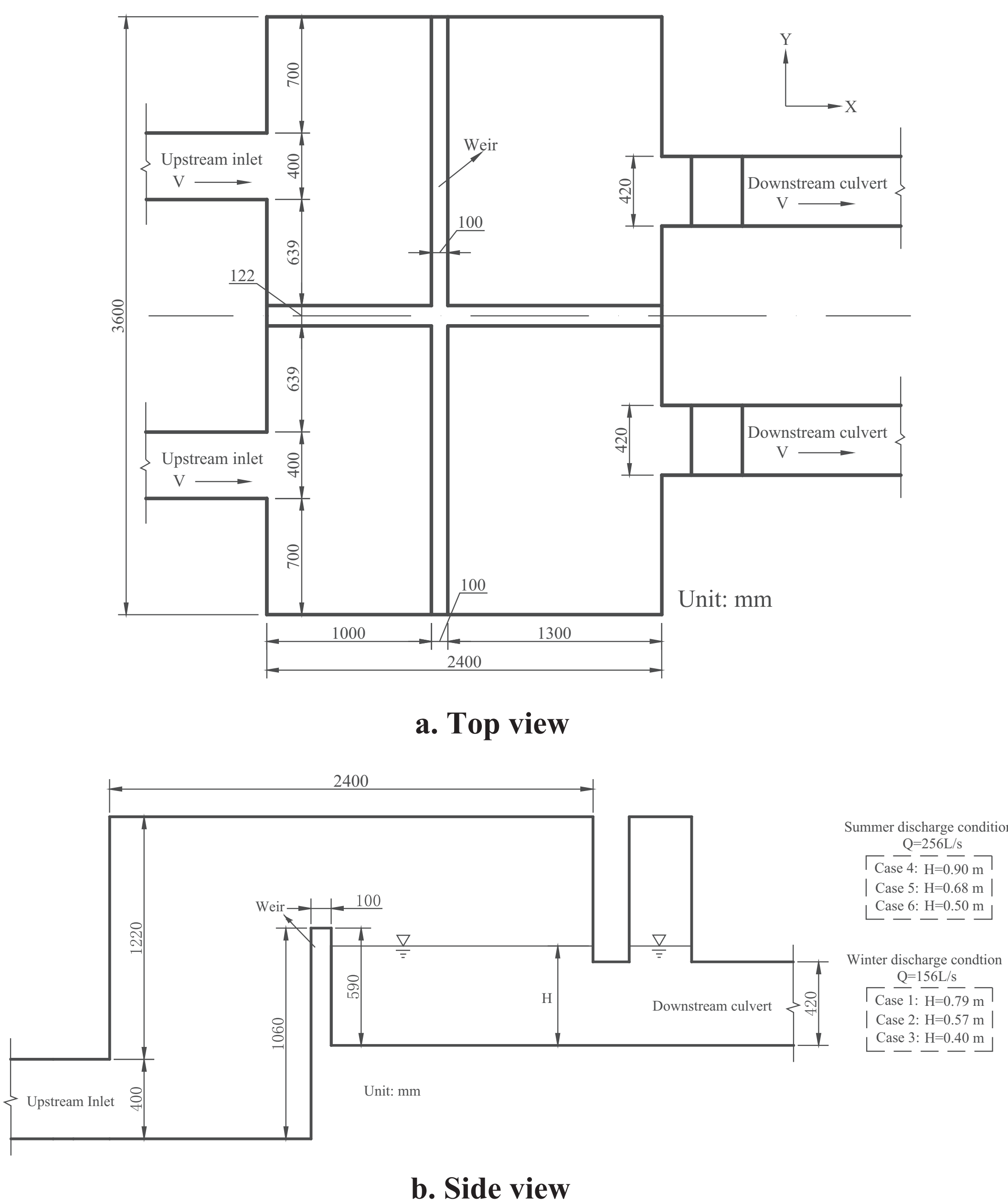

Fig. 1. Original siphon well design.