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Experimental assessment of the stage–discharge relationship of the Heyn siphons of Bric Zerbino dam

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ABSTRACT

The Ortiglieto reservoir, in the Piedmont region of Northern Italy, was created barring the Orba River with two dams: the main one, Bric Zerbino, having spilling facilities, the secondary one, Sella Zerbino, without spillways. On 13th August 1935, a heavy storm hit the Orba river basin. The water level in the reservoir increased by more than 10 m, as the spillways were unable to release the inflowing discharge, overtopping both dams. The Bric Zerbino dam was not damaged, while the Sella Zerbino dam collapsed, flooding the downstream valley and the small towns of Molare and Ovada. A 1:30 scale model of one of the siphon spillways of the Bric Zerbino dam was built to estimate its stage–discharge relationship and the maximum discharge released during the 1935 tragic event. Three piezoelectric pressure transducers and an ultrasonic level gauge were used to determine the hydraulic performances of the siphon.

1. Introduction

Bric and Sella Zerbino dams were built across the Orba River to form the Ortiglieto reservoir in the Piedmont region, Northern Italy. The original design was modified several times from 1898 to 1926 to increase the storage capacity of the reservoir from 12 to 18 hm^3 [2]. The 1921 design included a series of Heyn siphons with a total discharge capacity of 553 m^3/s. They were replaced in the January 1924 project with chute spillways providing a discharge capacity of 800 m^3/s, but were reintroduced in the May 1924 revision, which included a battery of 12 Heyn siphons, capable of spilling 520 m^3/s for the maximum storage elevation of 323 m a.s.l.

The Heyn siphon was patented in 1927 by Heyn [8]. The Gregotti type siphon, which was more popular at the time, was not adopted in this case since the outflowing water would have hit the downstream dam wall, which was not allowed by regulations.

Reservoir operations began in January 1925. The Bric Zerbino main dam was equipped with: (a) 12 Heyn siphon spillways, whose total discharge capacity was 520 m^3/s; (b) a side spillway capable of conveying 160 m^3/s; (c) a drop inlet controlled by a bell valve with 200 m^3/s discharge capacity; and (d) a bottom outlet capable of spilling 50 m^3/s. The Sella Zerbino secondary dam had no spillways.

During the 1935 event, only the siphons and the side spillway of the Bric Zerbino dam released water. The bottom outlet was kept shut to avoid dam vibrations and the bell valve of the drop inlet was clogged by mud after 15 min of operations. The remaining spillways were not able to release the incoming flood, leading to the overtopping of both dams. Due to erosion at the foundations, the Sella Zerbino dam collapsed. The dam break wave flooded the Orba valley, causing more than 100 casualties in the towns of Molare and Ovada [13,14].

Siphon spillways were widely used in dam construction in the 20th century, due to their capacity to convey discharge with small increases in upstream head. Moreover, their operations are completely automatic and they are relatively maintenance-free.

Considerable research has been carried out on siphon spillways operation principles [7,9,10,12,15-20]. In Drouhin et al. [4] a full-scale siphon was studied to examine the hydraulic behavior of the Fergoug dam in Algeria. Experimental tests on a shaft spillway outfitted with a hood in order to function as a siphon can be found in Aguralioglu and Muftuoglu [1]. Ervine [5] identified four operating modes for siphon spillways: weir flow, sub-atmospheric weir flow, partial flow and backwater flow. More recently, pressure was measured inside hydraulic models of siphon spillways, comparing the results with those given by commercial CFD packages [6].

The present study focuses on the hydraulic performance of the Heyn siphons installed at Bric Zerbino dam, to analyze their operations and to determine the discharge released during the 1935 tragic event. Model tests were undertaken to evaluate the

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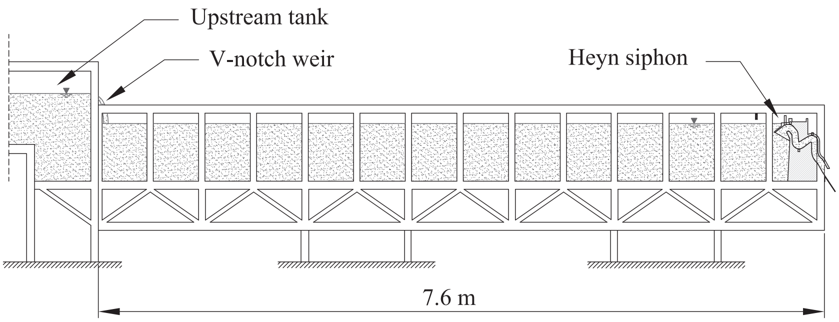

Fig. 1. Longitudinal profile of the siphon model experimental setup.

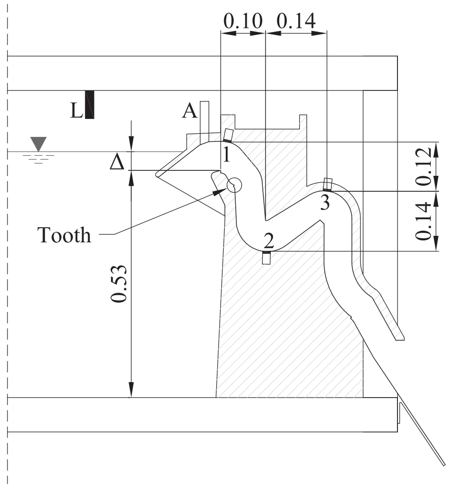

Fig. 2. Side view of the siphon model and of the measurement instruments locations (dimensions in meters).

discharge capacity of a single siphon spillway and the required water elevation for its priming.

2. Physical model of the siphon spillway

A 1:30 Froude similitude scaled hydraulic model of one of the Heyn siphon spillways of the Bric Zerbino dam was studied in the Hydraulics Laboratory of the University of Pavia (Figs. 1 and 2). The siphon was placed at the downstream end of a 9.3 m long by 0.48 m wide horizontal flume with steel bottom and glass side walls. Water supply was provided by the hydraulic circuit within the laboratory. A V-notch weir was used to measure the inflowing discharge.

The wooden siphon model, of rectangular inner section (10.0 cm wide by 6.7 cm high), has three elbows, indicated with the numbers 1, 2 and 3 in Fig. 2. Moreover, it has an aeration orifice indicated with the letter A. The water head over the siphon's crest is indicated with Δ. A small tooth, located immediately downstream of the siphon's crest and highlighted in Fig. 2, creates depression in the falling vein. Its effects will be discussed later in the manuscript.

Three PROTRAN PR3110 piezoelectric pressure transducers, T1, T2 and T3, were placed at the siphon elbows 1, 2 and 3, respectively to record pressures during the experimental tests. An ultrasonic level gauge PIL P43-F4Y-2D-1C0-330, indicated with L in Fig. 2, was placed upstream of the siphon in order to measure the inflowing water elevation Δ. Data acquisition frequency of the pressure transducers and of the level gauge was set to 200 Hz. All of the instruments have a precision of ± 1 mm. A high speed camera, placed on the side of the siphon, was also employed to capture each experiment.

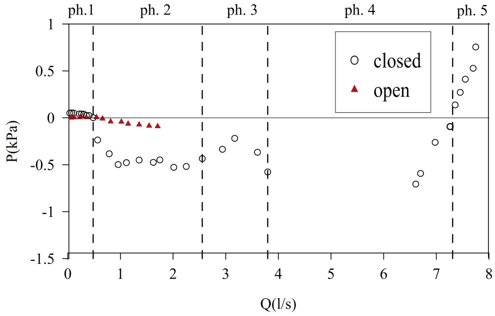

Fig. 3. Pressures measured by transducer T1 for increasing discharges.

3. Results and discussion

A total of 54 tests were performed under steady state conditions over a discharge range of 0.03–7.74 l/s, corresponding to 0.19–38.2 m^3/s at the prototype scale. Pressures inside the siphon and upstream water level were measured in each experiment. Tests were carried on until mean and standard deviation of the signals from each monitoring device were constant.

For discharges lower than 2 l/s, tests were performed for both closed and open air intakes; for higher discharges, only the closed intake scenario was evaluated. Unless specified, closed air intake conditions are always referred to in the text.

The experiments were carried out for both increasing and decreasing discharges. An hysteretic behavior was observed in the stage–discharge relationship of the siphon, as discussed by Aguralioglu and Muftuoglu [1].

Fig. 3 shows the pressures measured by transducer T1 at the upstream elbow 1 for experiments carried out with increasing discharges. The void in the discharge range between 3.8 l/s and 6.6 l/s is caused by the unstable priming of the siphon, which does not allow to achieve steady state conditions. To collect experimental data inside this discharge range, tests had to be carried out for decreasing flow rates (Fig. 4).

Positive pressures are always measured by the T2 transducer, as shown in Fig. 5. Pressures measured by the T3 transducer are instead around zero as long as the instrument is exposed to downstream air, subsequently following the trend of pressures at T1 and T2 when the siphon runs full, being smaller than those due to head losses (Fig. 6).

Five operating phases were distinguished for the siphon, indicated with dashed lines in Figs. 3–6. Table 1 lists the identified phases, alongside to the corresponding photographs of the experiments.