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The effect of increasing the number of cycles on the performance of labyrinth side weir

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ABSTRACT

Side weir is one of the most common hydraulic structures, which is used as a deviatory structure in rivers, irrigation and drainage channels and also in urban sewage collection systems. One of the ways to improve the efficiency of the performance of the side weir is changing the geometry of the weir.

The effect of deformation and cycle number increase on the hydraulics of the flow was investigated in the side weir, through conducting 360 experiments on the labyrinth weir in three cycles 2, 1 and 4 and the discharge coefficient was obtained for different modes. The results showed that cycle number increase leads to the reduction of flaws such as Eddy flows, decrease of weir input and sudden flow increase along the weir and it also reduces the projection length of the weir. The results indicated that the weirs with cycles 1 and 2 have higher C_m. Also, upon comparison with rectangular weirs, labyrinth weirs increase C_m 1.5 to 3 times and 30% in comparison with modified oblique side weirs (in all cycles).

1. Introduction

Side weir is a fixed structure on one side or both sides of the main channel. When the water surface reaches a certain level (weir crest), the extra water flow flows on the side weir. The inundation in this structure is gravitational and it is widely used because the transferred flow is continuous and no extra energy is spent to transfer water (such as pumping stations). These weirs are used in irrigation and drainage channels or in sewage transfer channels. It is also used as a deviatory structure in rivers and channels in order to control the flow. Moreover, it is also used as a protective structure in reverse siphons upstream and underpass of the roads. In the most usual form of side weirs, the rectangular weir is placed in the channel parallel to the flow direction. In this mode, the side weir (water transfer channel) is at an angle with the main channel.

The type of the flow on the side weir is locally variable with flow decrease. The locally variable flow is a mode of continual flow where flow intensity increases or decreases along the path. The flow in side weirs is basically a branch flow. Flow distribution is done along the flow path.

Numerous theoretical and laboratory studies have been conducted to investigate the energy changes along the branch flow. Most of the researchers believe that energy should be considered constant along the path. They believe that the branching of the flow does not lead to energy reduction or that the amount of energy reduction is negligible compared to the reduction caused by friction. The studies conducted by De-Marchi in 1934 [3] can be considered as the base and foundation of this theory and also subsequent studies on side weirs. De-Marchi presented a relationship for the flow on these weirs using the energy equation, assuming that the specific energy is constant along the side weir.

$$\frac{-dQ}{dx}=\frac{2}{3}C_m\sqrt{2g}(y-w)^{1.5} \tag{1}$$

In Eq. (1), dQ/dx is the flow change along the weir, C_m is the discharge coefficient of the side weir (De coefficient), g is the gravitational acceleration, y is the flow depth, and w is the height of the weir.

De-Marchi stated that the discharge coefficient of side weirs is a function of hydraulic and geometric and flow variables and De-Marchi presented a relationship to obtain the length of the weir.

$$L=\frac{3}{2}\frac{B}{C_m}(\varphi_2-\varphi_1) \tag{2}$$

in which L is the length of the weir crest; B is the width of the main channel; C_m is local discharge coefficient known as the

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Nomenclature

C_m	De-Marchi coefficient of discharge
y_1	upstream depth
y_2	downstream depth
Q_1	upstream discharge
Q_2	downstream discharge
Q_w	weir out flow discharge
v	average velocity
Fr	Froude number
L	weir length
s	channel slope
w	weir height
E	specific energy
l'	length of weir crest
B	width of main channel
θ	bike angle
v_1	average velocity in upstream of main channel
h	projection length of the weir

De-Marchi coefficient; φ is varied flow function; and subscripts 1 and 2 represent immediate upstream and downstream of the weir.

De-Marchi demonstrated that the flow profile is not linear and is curved. Also, De-Marchi showed using the sign of Eq. (1) that the flow profile is ascending in the subcritical mode and is descending in the super-critical mode.

Lots of studies were conducted on the side weir after De Marchi [3], most of which pertain to conventional side weirs. In many of these studies, C_m was only considered as a function of the Froude number of the flow in upstream [2,7,9,11,16,22].

Swamee et al. [23] investigated the analysis method of side weirs using elemental flow intensity coefficient. In their study on the conventional side weir, Singh et al. [10] came to the conclusion that C_m is a function of w/y_1 in addition to Fr_1. By conducting extensive experiments on side weirs, Borghei et al. [1] stated that the slope of the main channel does not affect C_m significantly in subcritical flows and they presented a regression relationship using three parameters Fr_1, w/y_1, and L/B in order to calculate C_m. Emiroglu et al. [13] conducted experiments on rectangular sharp-edged weirs and they reported that there is a direct relationship between C_m and Fr_1 where $(L/B) \geq 1$. They also stated that the effects of the parameters L/B and L/y_1 cannot be overlooked.

Also, some researchers such as Sarginson [17] investigated the effects of surface tension on rectangular weirs and he presented relationships to calculate C_m using We numbers. Using the momentum equation, El-Khashab and Smith [21] obtained a relationship for the ruling flow on side weirs. They commented that in case the velocity of the branch flow on the longitudinal axis of the main channel (u_x) is greater than the average velocity of the main channel (v), the assumption that energy is constant along the weir is not true.

There have also been researches on side weirs in non-rectangular channels, such as, circular, triangular, trapezoidal, and U-shaped channels and certain equations have been presented to determine the flow passing on the weir and to calculate C_m in these channels [22,25,26]. Kumar and Pathak [15] studied the discharge coefficient of sharp and broad-crested triangular side weirs. Hager [19] studied the supercritical flow in the circular-shaped side weirs.

In the year 2001, Ura et al. [20] conducted analytical and experimental studies on oblique side weirs. They believed that conventional side weirs have innate deficiencies such as the flow separation phenomenon and flow coefficient decrease with the increase of Froude number in the main channel. By conducting various experiments on oblique side weirs, they came to this conclusion that the best mode is when the weir is at a 70° angle with the main channel. They also presented a relationship to estimate C_m in terms of Fr_1 and the placement angle of the oblique side weir θ. Some scientists study on side weir discharge coefficient with numerical method [14,27,28]. Nekoie in 2007 conducted some experimental studies on labyrinth side weir [18]. Emiroglu et al. [4] investigated labyrinth side weirs in one cycle. The results of their experiments showed that labyrinth side weirs with a vertex angle of 45° have a higher C_m. They also stated that the flow coefficient of the weir increases with the increase of upstream Froude number. In 2010, Kaya et al. [6] conducted experiments on semi-elliptical weirs in rectangular and prism channel under subcritical flow conditions. They commented that when the ratio of the two diagonals of the ellipse is 1.5, semi-elliptical weirs have better performance and have a greater C_m. In 2010, Emiroglu and Kaya [12] investigated labyrinth weirs with trapezoidal layout. They stated that with the decrease of the angle of the trapezoidal weir wall (θ) and the increase of the effective length of the weir, C_m increases. The results they achieved showed that $\theta = 16°$ is the best mode among the angles under experiment. They commented that labyrinth weirs with trapezoidal layout increase the flow discharge coefficient 1.5 to 5 times compared to the conventional side weir. Borghei and Parvaneh [8] worked on a modified oblique weir having two cycles and they stated that the weirs on which they experimented, increases C_m as much as 20% compared to the oblique weir under experiment by Ura et al. [20] and as much as 35% compared to conventional weirs. Also, some scientists simulated water surface profile on labyrinth side weir and predicted discharge coefficient with Fluent [24]. Table 1 shows the different equation proposed by some researches.

In view of the investigations conducted on oblique side weirs, more research and experimentation on side weirs with various crest shapes and in different plans is required to be able to improve the performance of the side weir and reduce its innate flaws. The general objective of this research is to investigate the efficiency and replaceability of weirs with different plans with conventional weirs. To this end, studies were conducted by selecting the labyrinth weir in three different cycles and by changing hydraulic and geometric parameters pertaining to the channel and weir. Hence, 360 experiments were conducted for different values of vertex angles of weirs (θ), weir length (L), weir height (w), and input flow (Q_1) of labyrinth side weirs in three cycles $n = 1, 2, 4$. Flow surface profile in the main channel and flow intensity coefficient were investigated and eventually, four new relationships were presented to calculate C_m.

2. Material and methods

Experimental setup consisted of a main channel and a bench channel Fig. 1. The main channel had rectangular shape with 10 m long, 0.3 m wide, 0.5 m deep and 0.0001 bed slope. Main channel contained a horizontal steel bed and vertical glass sidewalls. The bench channel whose bed and sidewalls were made of steel with 6 m long, 0.4 m wide, 0.5 m deep and a horizontal bed. Also this channel was parallel with main channel. The side weirs were located 5 m from the upstream of main channel.