EFFECTS OF VERTICAL DEFLECTORS ON ROOSTER TAIL GEOMETRY

Stefano Pagliara [1], Sahameddin Mahmoudi Kurdistani[2] and Michele Palermo[3]
[1]Dept. of Civil Eng., University of Pisa, Italy, s.pagliara@ing.unipi.it
[2]Dept. of Civil Eng., University of Pisa, Italy, s.m.kurdistani@dic.unipi.it
[3]Dept. of Civil Eng., University of Pisa, Italy, michele.palermo@ing.unipi.it

Abstract

Behind piers across spillway, super critical flow generates standing waves known as rooster tails. One of the most important parameter which has to be evaluated is the height of rooster tail. In fact, high rooster tails, especially occurring close to the side walls, increases the construction cost, as countermeasures to contain them have to be adopted. In this study, the scale model of the El Chaparral dam, with a downstream chute expansion of 50° slope, has been used and the maximum flood was simulated. Experiments have been done with different angles of vertical deflectors for different Froude numbers. The aim of the paper was to optimize the angle of vertical deflectors to minimize rooster tail height.

Introduction

Behind gate spillway piers, flows are generally supercritical (Reinauer and Hager 1994) and standing waves called rooster tails take place. The first contribution on supercritical flow behind chute piers was given by Koch (1982). He tried to reduce the height of rooster tail using a separating wall as a twin bottom outlet. Slopek and Nunn (1989) carried out a series of prototype tests on freeboard design in chutes. They compared the results with some empirical freeboard equations. They found that empirical equations always overestimate the freeboard, except when standing waves behind chute piers occurred. Reinauer and Hager (1994) studied the standing wave patterns generated by piers in a horizontal channel. They found that the ratio of the approach flow depth to the pier width characterizes the standing waves. Also they carried out some experiments to reduce the height of the rooster tail with an asymmetric pier extension. Generally, along with standing waves below chute piers, shockwaves occur and characterize the surface flow patterns (Vischer and Hager 1998). Reinauer and Hager (1996) conducted a series of experiments on aerated flows. They found that a shockwave can act as a localized aerator. In addition, Reinauer and Hager (1997) analyzed rooster tail in sloping chutes, confirming that the results of Reinauer and Hager (1994) are still valid and concluded that the wave heights are identical if measured perpendicular to the chute bottom. Carnacina et al. (2010) conducted a series of experiments on effects of deflector ramps on rooster tail geometry using El Chaparral dam 1:75 scaled model. Results showed that the presence of the deflector ramp downstream of the chute can increase the rooster tail height if the inception point is close to the ramp, even for approach Froude numbers smaller than 5. Pagliara et al. (2011) analyzed characteristics of rooster tail wave in chutes. The results indicate that the rooster tail wave height is significantly influenced by b_o/b_p, in which b_o is the distance between piers across the spillway and b_p is the pier width. They developed new expressions for estimating the rooster tail maximum wave height in terms of β and l_r, where β is the angle of the deflector ramp with the chute bottom and l_r is the length of deflector. The results showed that for $x_r/x_a = 2.16$, the maximum wave height occurs, where x_r is the distance of the deflector ramp from the end of the pier and x_a is the position of rooster tail inception point respect to the pier end. Air concentration measurements exhibited that aeration increases with the approach Froude number and also with the deflector ramp slope .The aim of the present study is to experimentally analyze the effects of vertical deflectors on rooster tail formation downstream of spillway piers. The model includes aerator deflector ramp and different tested inlet flow conditions. This study aims to optimize the vertical deflector angle to minimize the height of rooster tail.

Experimental setup

The 1:75 scaled model of El Chaparral dam has been used to conduct the experiments. The model was made of one horizontal rectangular channel (1.2 m wide, 6.0 m long and 0.6 m high) whose dimensions are suitable to obtain stable inflow conditions at the beginning of the spillway. A rectangular Perspex sloped chute, 0.753 m wide, 1.084 m long, 0.45 m high and 50° steep was connected to a ogee-crested spillway with four radial gates. All parts of the model including channel and the downstream basin were made of Plexiglas in order to allow visual observation of the phenomenon. The model set-up apparatus is shown in figure 1.

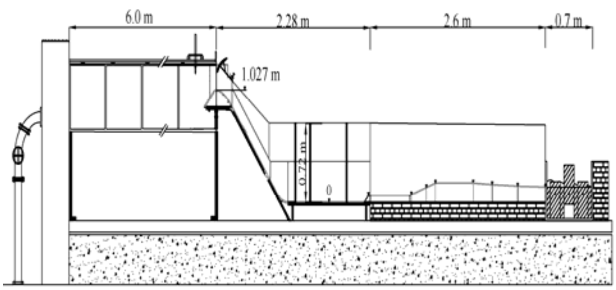

Fig. 1 – Sketch of the model apparatus

Figure 2(a) shows the longitudinal view of the model including indication of the main parameters of the standing wave. x_m is the distance of the section in which the maximum rooster height h_m occurs and h_0 is the flow depth in section (0-0). Figure 2(b) shows a plan view of the model. The deflector ramp is located at 0.237 m from section (0-0) (i.e. the section in correspondence with the downstream piers edges, see Figure 2b). The ramp is 0.08 m long and its slope is β=5.7° respect to the bed plane. A pair of vertical deflectors with variable angle of the same height of piers is attached to the end of each pier. The length of the vertical deflectors is 0.0155 m.

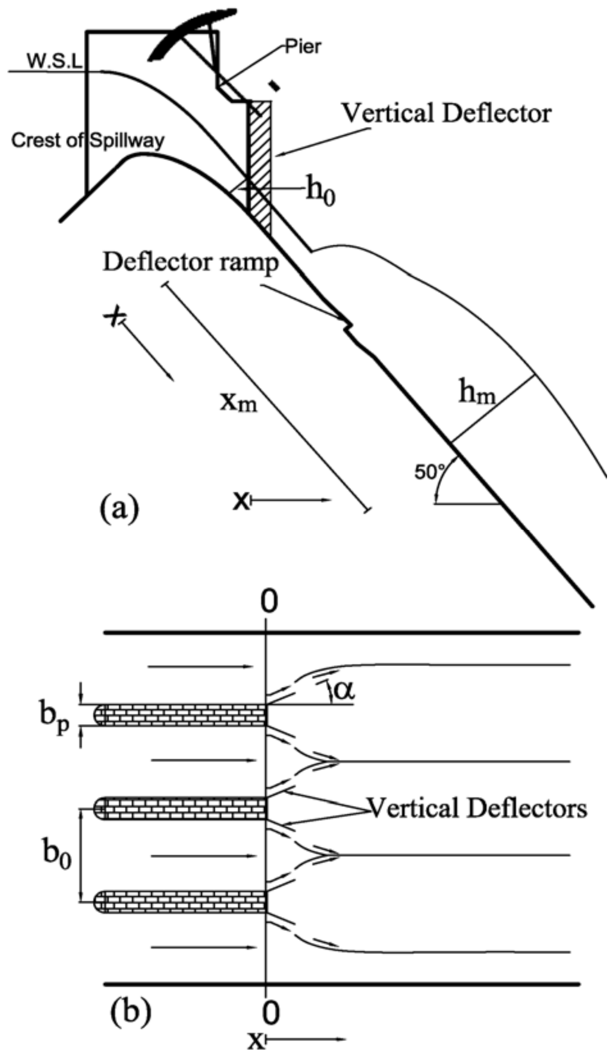

Fig. 2 - (a) Longitudinal and (b) plan views of the adopted model

A point gauge 0.1 mm precise was used to measure the flow depths. A rating curve based on volumetric discharge measurements (2% accuracy) was used to define the flow discharges. Each gate is 0.153 m wide and 0.23 m high. There are four gates and three piers whose width is 0.047 m. Discharges up to 102.6 l/s were tested. In all experiments, the width of piers was constant. The approach Reynolds number varied from 8.4E+4 to 1.3E+5. The experimental details are shown in Table 1. h_0' is the approach flow depth close to the side walls.

Table 1 - Experimental conditions

Q (l/s)	b_0 (m)	b_p (m)	h_0 (m)	h_0'(m)	F_0	$R_e \cdot 10^{-4}$
61.6	0.08	0.047	0.050	0.054	2.87	8.4
82.1	0.08	0.047	0.062	0.068	2.77	10.8
102.6	0.08	0.047	0.077	0.092	2.51	12.9

Results and discussion

For experimental conditions listed in Table 1, the rooster tail and the water surface profiles close to the side walls were measured varying the angle α i.e. the opening angle of vertical deflectors expressed in degree, as shown in Figure 2b. Figure 3 compares the El Chaparral dam model data for α=0 with previous studies results. Carnacina et al. (2010) showed that the presence of the deflector ramp downstream of the chute can increase the rooster tail height if the rooster tail inception point occurs over the ramp. Figure 4 shows that for α=0 the inception point of rooster tail is not over the ramp and the current study data are in agreement with Eq. 1 proposed by Reinauer and Hager (1994).

$$\frac{h_m}{h_0} = 2.5\left(\frac{h_0}{b_p}\right)^{0.5} \qquad (1)$$

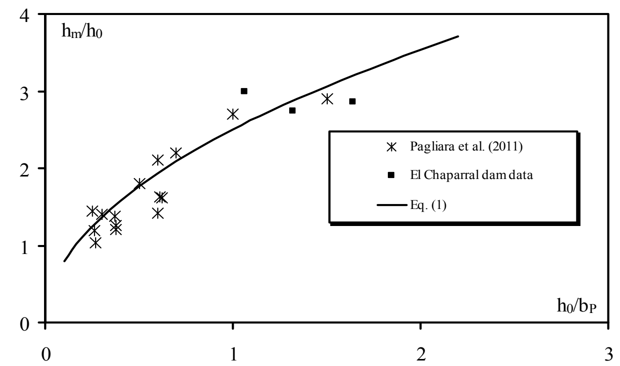

Fig. 3 – Comparison of El Chaparral dam model data with previous results of Pagliara et al (2011) along with Eq. (1)

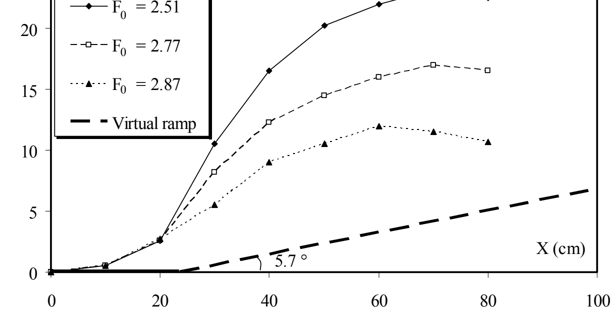

Fig. 4 –Position of inception point of rooster tail profiles obtained with vertical deflectors for α=0

The results of measurements for α between 0 and 20 for three different approach Froude numbers show that the lowest height of rooster tail occurs for 10≤α≤12 (Fig. 5).

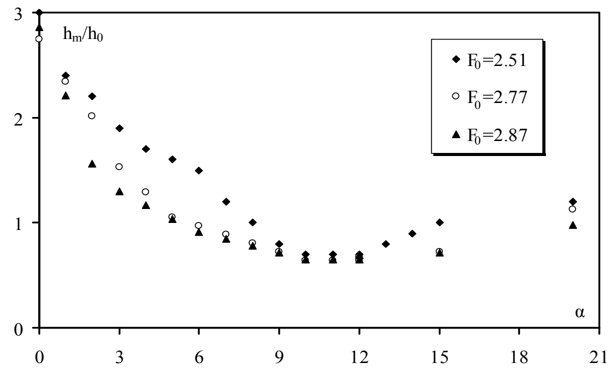

Fig. 5 – Effect of α on h_m/h_0 for the tested Froude numbers

Figure 6 compares the results in the presence of vertical deflectors for different approach flow Froude numbers with rooster tail general equation derived by Reinauer and Hager (1994). It can be observed that the vertical deflectors can reduce the height of rooster tail more than three times. Figure 7 (a,b) show the lateral and frontal view of rooster tail for α=0, whereas Figure 7(c,d) shows the same for α=12.

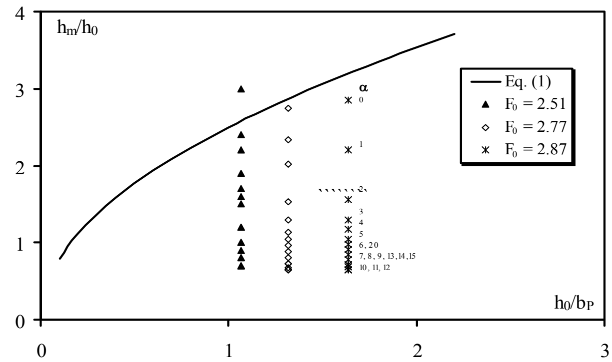

Fig. 6 – Effect of vertical deflectors on the height of rooster tail

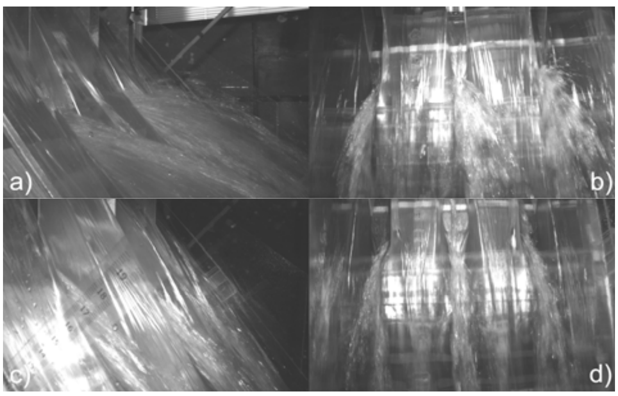

Fig. 7 – a) Lateral and b) frontal view of rooster tail for α=0; c) lateral and d) frontal view of rooster tail for α=12.

In addition, water surface profiles close to side walls have been measured too. The results show that the lowest flow depth occurs for α=4 (Fig. 8). In Figures 4 and 5, it was shown that the lowest height of rooster tail occurs in range of 10≤α≤12. But for design purposes the flow depth close to side walls is very important as the side walls height is depending on it. Thus α=4 is the optimum opening angle for vertical deflectors as at the same time it can assure both rooster tail height reduction and a minimization of the water surface profiles close to the side walls.

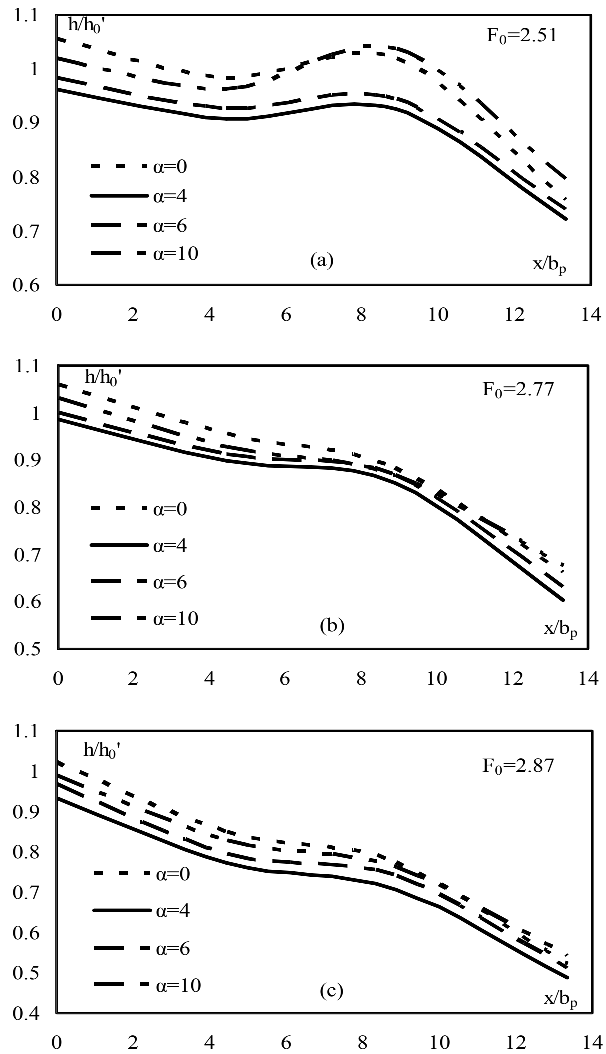

Fig. 8 – Effect of vertical deflectors on water surface profiles close to side walls for a) F_0=2.51, b) F_0=2.77, c) F_0=2.87.

Conclusions

The effect of vertical deflectors on super critical flow downstream of chute for a 1:75 model scaled dam has been analyzed. Results showed that an increase of α up to 12, reduces the height of rooster tails. Side walls flow depth measurements show that α = 4 is the optimum opening angle for vertical deflectors in order to minimize water surface profile close to side walls.

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