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ORIGINAL ARTICLE

Effect of stilling basin shape on the hydraulic characteristics of the flow downstream radial gates

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Abstract Barrage regulators are considered as one of the most important projects in the Egyptian irrigation practice, which is obvious by its controlling of the released discharge and both of upstream and downstream water levels. In the present time, the ministry of water resources and irrigation starts to construct new barrages on the River Nile instead of the oldest ones, which are not able to withstand the requirements of increasing head difference between the upstream and downstream water levels upon the gates. The present study was focused on investigating the effect of different shapes of stilling basins of regulator on the length of the submerged hydraulic jump, velocity profiles along the apron, and local scour downstream regulator floor. Extensive experimental program was conducted on a re-circulating flume with 1.0 m wide, 26.0 m long and 1.2 m deep, with discharges range from 40 to 190 l/s. The relative velocity near bed, and shear Reynolds number were studied to fix the best shape of stilling basin that could reduce both of length of submerged hydraulic jump and local scour downstream stilling basin. Statistical equation was developed to correlate the length of submerged jump with the other independent parameters. Finally, clear matching of results from the length of jump and velocity analysis was investigated.

1. Introduction

The Ministry of Water Resources and Irrigation in Egypt started to construct new barrages on the River Nile instead of the oldest ones to withstand the increased difference of water levels over the gates of regulators. The oldest regulators were built from long time, such as, Esna Barrage (1908), Naga Hammadi Barrage (1930), Assuit Barrage (1902), Delta Barrage (1939), Zefta Barrage (1902), and Idfena Barrage (1950). The present study focused on studying different shapes of stilling basin of Naga Hammadi Barrage under the submerged flow condition. The submerged hydraulic jump formed

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Nomenclature

b	the flume width	u_1	super critical velocity
D_s	maximum scour depth downstream stilling basin	u_m	maximum velocity at certain cross-section
D_{50}	mean diameter of rip rap	u_b	velocity near bed
Fr	Froude number	y_1	super critical flow depth
h	height of drop under radial gate	y^-	minimum distance allowed from electromagnetic current-meter to the bed
x	distance beginning from the radial gate	y_3	back up water depth
L	basin length	y_t	tail water depth
L_j	length of submerged hydraulic jump	α	inclination angle below gate
S	submergence ratio		
u	velocity at certain height from basin		

downstream these barrages possesses its importance since used as energy dissipation device. Enormous research studies, dealing with submerged hydraulic jump, were carried out. Govinda Rao and Rajaratnam [10] studied experimentally the submerged hydraulic jump in rectangular channels. The submerged jump as the case of a plane turbulent wall was described by Rajaratnam [19,20]. Narasimhan and Bhargara [17] studied the pressure fluctuation in a submerged jump downstream of a sluice gate. McCorquodale and Khalifa [16] studied experimentally and theoretically the submerged radial hydraulic jump. El-Azizi [5] examined the submerged hydraulic jump experimentally under different flow conditions. Smith [24] studied the submerged hydraulic jump in an abrupt lateral expansion. Long et al. [14], Fuxima and Prinos [9], and Ma et al. [15] clarified numerically the submerged hydraulic jump. Ohtsu et al. [18] studied the submerged hydraulic jump below abrupt expansions. Flokstra [8] investigated a numerical model for submerged vanes. Brett and Gregory [2] investigated submerged and unsubmerged natural hydraulic jumps in a bedrock step-pool mountain channel. Subhasish and Arindam [25] investigated the characteristics of turbulent flow in submerged jumps on rough beds.

On the other hand, a large number of researchers studied scour characteristics downstream prismatic stilling basin, such as, Rajaratnam and Beltaos [21], Rajaratnam and Macdougall [22], Hassan and Narayanan [12], Khalifa et al. [13], and Habib et al. [11]. Ali [1] investigated the best location of baffle sill and different variables affected upon the local scour downstream hydraulic structures. El Masry and Sobeih [4] investigated experimentally the influence of spacing between double submarine pipelines on local scour. El-Gamel [6] studied experimentally the effect of using three lines of angle baffles on scour downstream heading-up structures. El-Gamel et al. [7] introduced an experimental study to investigate local scour DS hydraulic structure. Saleh et al. [23] investigated experimentally the effect of end-sill on scour downstream sudden expanding stilling basins with different expansion ratios. Claudia and Giampiero [3] investigated numerically scour due to a horizontal turbulent jet. The present study aims to investigate the effect of stilling basin shape on the length of submerged jumps and the velocity profiles along stilling basin and behind it. Moreover, this study will clarify local scour downstream regulator for typical cases for all studied shapes of stilling basin. Certainly, the best shape of stilling basin could share in the long time stability of such huge hydraulic structures.

2. Experimental work

The experiments were conducted using a 1.0 m wide, 26.0 m long and 1.2 m deep flume. The flume is provided with a recirculating system. Radial gate was constructed at a distance of about 12.0 m downstream the flume inlet. The stilling basin was provided with two half-piers (9.5 cm thick each) symmetrically installed on both wall sides. Two pumps, with capacities 500 and 150 l/s were connected with two pipelines 16 and 10 in., respectively, to satisfy a maximum capacity of 650 l/s. An ultrasonic flow-meter was used for measuring the discharge during the tests.

An electromagnetic current-meter was used to measure the velocity profiles at different cross sections over the regulator basin. Moreover, an electromagnetic current-meter was used to allocate the end of submerged jump. The electromagnetic current-meter traced the positive and negative values of the flow velocity on the top water surface layer; distance from zero velocity point to radial gate represents the length of the submerged hydraulic jump. Different shapes of stilling basins were experimentally tested as shown in Fig. 1. For each one, six different flow conditions and six different tailwater depths were tested. Table 1 provides typical conditions used in experimental work for different shapes tests. The discharge was changed from 40 to190 l/s, to cover the different submergence and Froude numbers for each shape. Both of shape I and III have sill under the radial gate with inclination angle (α) = 30°, height (h) = 0.17 m, and 0.09 m, respectively. But, shape IV has sudden drop with height (h) = 0.09 m. The stilling basin in shape II has flat shape. For shape V, the stilling basin has flat shape provided with positive multi-step with total height 0.09 m (2.25, 18.6 cm for the height and the length of each step, respectively) at the end of basin, see Fig. 1. The flow velocity was measured using an electromagnetic current-meter type EMS, manufactured by Delft Hydraulics, Holland. The current-meter was connected to a data logger, which receives the data directly from the current-meter. The data logger also was connected to the computer, which receives the data from the data logger and save it in a file. The data logger was set to record 25 readings during time of 10 s at each point depth of the cross section. The flow velocity was measured at seven cross sections with equal distances apart. The distance between each two cross sections was equal to 0.50 m. The first cross section was located at distance of 1.0 m downstream the gate. The velocity values were measured at four points along the water