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Static Pressure Analysis in Stepped Chutes with Inclined and Horizontal Steps in Nappe and Skimming Flow Regimes

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Abstract- Spillway is one of the most important parts of a dam to control the flood. Among different types of spillways, stepped spillways is one of the best energy dissipaters. By advances in technology and the satisfaction of two elements of safe and low cost construction the usage of stepped spillway is increased widely. Due to this fact, more studies are focused on the stepped spillways. Researchers made some efforts and proposed different methods to improve the efficiency of this structure to dissipate energy. Modification on step geometry, regarding flow regime type, is one of these efforts. Flow pressure and its fluctuations on the steps of the stepped spillways is one of the main factors affecting the design and safety of this structure. In this experimental research, reverse inclined steps have been applied in three degrees [0o (horizontal), 7o, 10o] to obtain static pressure in both nappe flow and skimming flow regimes of stepped spillways. Static pressure obtained from reverse inclined steps have been compared to the amount in horizontal step. Results indicate slight increase in energy loss rate when reverse inclined steps have been applied in nappe flow regime of stepped spillways.

Keywords- *Static Pressure, Stepped Spillway, Nappe and Skimming Flow*

I. INTRODUCTION

In the last two decades, extensive experimental research has been developed to characterize many aspects of stepped spillways. Some research works have been conducted on the pressure of steps in the stepped spillway to determine the amount of pressure fluctuations and pressure distribution on the vertical and horizontal sides of the steps. Gangfu Zhang et al. (2016) conducted new experiments in the developing flow region on a large 1V：1H stepped spillway model with step height h=0.10 m. The flow properties in the developing flow region were carefully documented. In the developing boundary layer, the velocity distributions followed a 1/4.5th power law at the step edges. Detailed velocity and pressure measurements showed some rapid flow redistribution between step edges and above step cavities. Results suggested that the spatially averaged dimensionless shear stress was comparable in the developing flow and fully aerated flow regions. Also, Gangfu Zhang et al. [1] studied on the total pressure fluctuations and two-phase flow turbulence in self-aerated stepped chute flows. The results demonstrated the suitability of miniature total pressure probe in both monophase and two-phase flows. Both interfacial and water phase turbulence intensities were recorded. Present findings indicated that the turbulence intensity in the water phase was smaller than the interfacial turbulence intensity. Lesleighter, Ej. et al. [2]studied on the flow behavior at the stair-stepped spillway chute with 2.4 m high steps, in particular the piezometric pressures and transient pressures on the tread and riser of the steps. The spillway chute converged from 100 m at the crest to 78 m at the bottom at entrance to the stilling basin; the unit discharge entering the stilling basin was 60 m2/s for the PMF. One of the particular interest of the research was the occurrence of negative pressures on the steps, and the paper described the transients for several discharges from the AEP 1 in 1,000 up to the PMF; the results indicating very low pressures into a cavitation region. The design provides for an aerator across the spillway in order to counter the effects of possible cavitation. Results was presented with and without the aerator operating. The paper provided useful design information for the hydraulic design of stepped spillways. Hamedi et al. has conducted the experiments on the stepped chute with reverse inclined steps to observe the efficiency of energy dissipation of stepped spillway [3] also they completed some series of experiments to determine the energy loss in different step modifications in the same physical model which has been used in this research [4-6]. Results shows that slight increase in energy loss rate when reverse inclined stepped applied. Moreover, recently, numerical methods have been widely used in engineering [7-11] Hamedi and Ketabdar,and Hamedi et al. simulated the numerical model to determine the efficiency of dissipation of stepped chute [12-13]. Results shows numerical model has a good capability to estimate the energy dissipation of stepped spillway. Many researches have been conducted to observe the effect of inclined steps degree on the energy dissipation rate [14-15]. Moreover, Ohtsu and Yasuda (1997) considered the characteristics of flow conditions on stepped channels [16]. Many studies have addressed different aspects of stepped spillways; and have made them known as an efficient energy dissipater [17-18]. Chamani & Rajaratnam (1994) conducted the extensive experiments on the Nappe flow regime and devloped experimental formulas to determine energy loss in this flow [17]. Ketabdar, Milad et al., conducted the experimental studies on the energy dissipation in nappe flow regime in the spillway with equipped inclined steps and sill. The results shows that inclined steps have a significant effect on the energy dissipation [19].

II. EXPERIMENTAL SET UP

The research was conducted at the Water Research Institute in Iran on a stepped spillway. The steps and walls were made of Plexiglas and mounted on a steel frame. The chute spillway was a broad-crested weir with 60 steps. In the present investigation, only four steps were reversing inclined; all were placed after the middle of the chute (steps 39-42). The horizontal length of the steps was 14 cm; the step height was 4.66 cm and the chute width was 1.33 m. The height of the broad-crested weir to the first step was 5 cm. Measured parameters during the test include depth and velocity. The experiments have been conducted for four discharges (20, 25, 30, and 35 l/s) in the Nappe Flow Regime and (70, 90, and 120 l/s) in the Skimming Flow Regime. Flow depth and velocity were measured by using a point gauge (with a precision of 1 millimeter) and a pitot-tube, respectively. Flow discharges were measured by the sharp crested weir at the end of the downstream chute. Two slopes of 7° and 10° about the horizon were used. The depth measurement included three depths of Jet 1 (only water), Jet 2 (a mixture of water and air), and Jet 3, which is spraying of the flow. Finally, an average of the three depths across each line of the piezometer was used as the step depth.

Static pressure measured with the use of piezometers installed in bottom of the model connected by hoses to the board of piezometers. Three piezometers were installed during each step and there were 3 rows of piezometers within each step: right, left and center. In fact, on each step nine piezometers are available. In each test, a picture was captured from the board of piezometers, in order to more accurately determine the height of the flow column. In order to measure the pressure fluctuations accurately, the transducer was used. Thus, the tip of the piezometers hose connected to sensors and the sensors were connected to the amplifier to boost the signal and amplifier is also connected to a computer and related software. Time to test was 30 seconds and the data was recorded by the rate of 200 per seconds. In this chute, only four steps (39-42) were reversely inclined. The depth and velocity and static pressure values were measured at these steps, as well as at the 38th step. Ease of Use

III. RESULTS AND DISCUSSION

Result shows that by increasing the discharge rate (ina constant slope), the static pressure is increased. Moreover, the static pressure at the middle of the step is higher than the static pressure on the right and left side of the steps in all discharge rates (Figures 1 and 2).

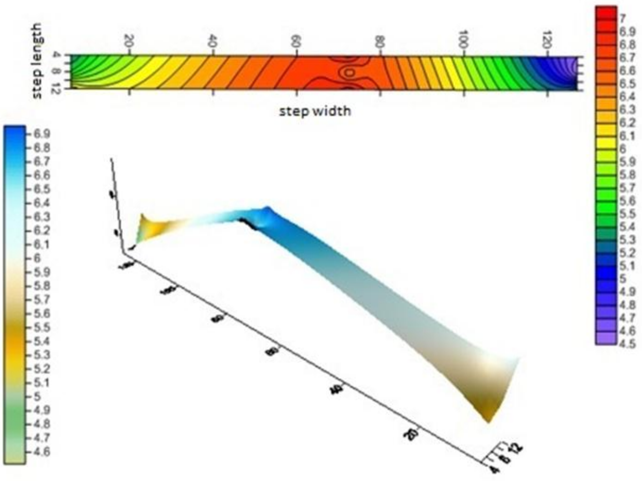

Figure 1. Pressure on the bottom of the steps in Discharge 30 liters per second and slope of 7 degrees

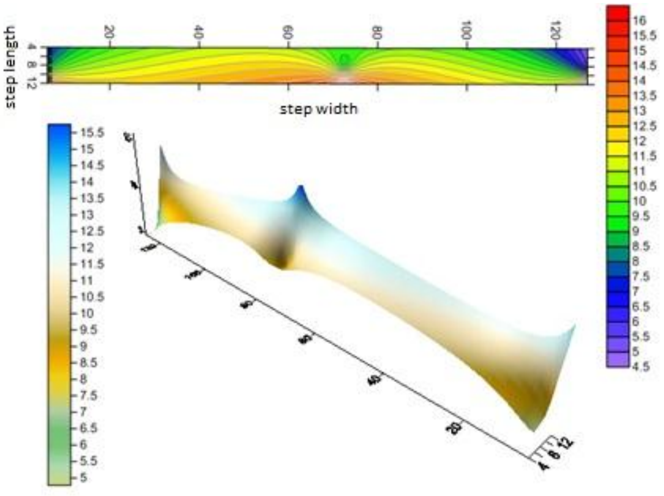

Figure 2. Pressure on the bottom of the steps in Discharge 90 liters per second and slope of 7 degrees

Result indicates that by increasing the slope of the steps with constant discharge, pressure is increased. In this case, as shown on the slope counters (Figures 3 and 4), the pressure on the right side has the lowest pressure value. In nappe flow regime and horizontal steps with increasing discharge rate pressure is increased.

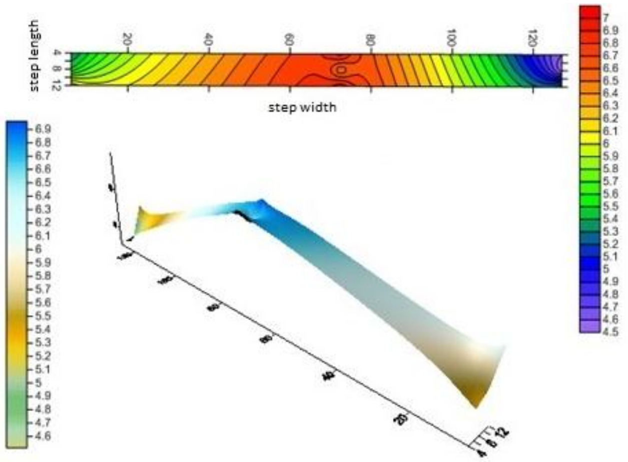

Figure 3. Pressure on the bottom of the steps in Discharge 30 liters per second and slope of 7 degrees

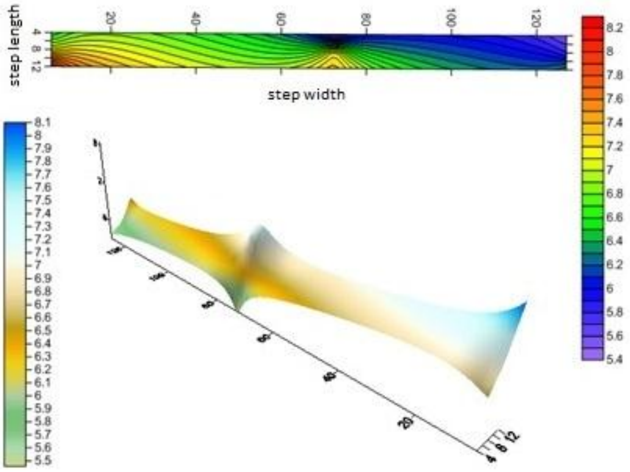

Figure 4. Pressure on the bottom of the steps in Discharge 30 liters per second and slope of 10 degrees

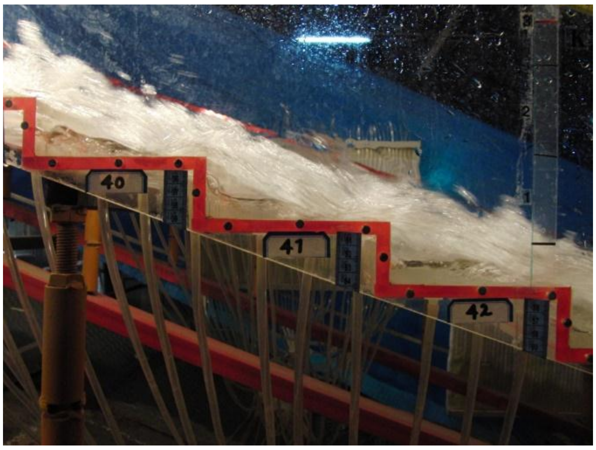

Figure 5. Nappe flow regime in Discharge 20 liters per second and flat steps

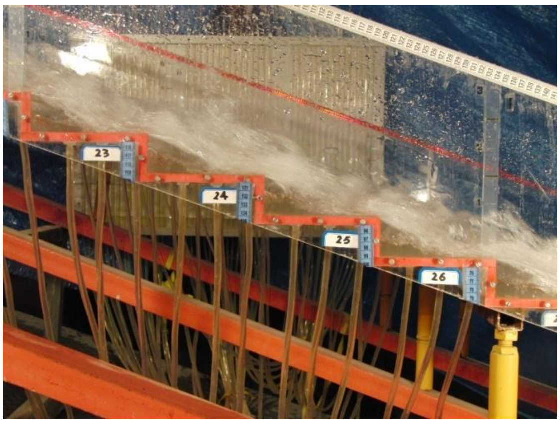

Figure 6. Nappe flow regime in Discharge 25 liters per second and flat steps

Figure 7. Nappe flow regime in Discharge 30 liters per second and flat steps

Pressure on the front row of piezometers in steps (The farthest row from the edge) is less than the amount of pressure on the other two rows at all steps during the chute. After the first row, the third row has the lowest pressure. The maximum pressure occurs in the second row at the middle of the steps. This is due to the jet on the steps which almost collided in the central area of steps. Moreover, pressure on the width of the steps in the chute is not constant and is fluctuating. Pressure fluctuations within the width of the chute could be occurred since the current instability in the first few steps of the chute with air discharge phenomenon causes surface instability throughout the whole structure.

In skimming flow regime with horizontal steps with increasing discharge rate, pressure is increased. Pressure on the front row has the maximum pressure value since the jet collides the bottom of the steps in this area. Unstable vortex at the end of the steps (farthest from the edge of the steps) creates little pressure on the bottom of the steps in this area.

In inclined steps in both nappe and skimming flow regimes and a constant angle with increasing discharge, pressure is increased. In nappe flow regime, the pressure increases gradually along the slope. It means that the least pressure from the first row will be transferred to the second row. In skimming flow regime, also the pressure increases gradually along the slope, the lowest pressure occurs in the first row of piezometers and the maximum pressure in the third row (edge of the steps) can be seen.

IV. CONCLUSION

The experiments have been conducted for four discharges (20, 25, 30, and 35 l/s) in the nappe Flow Regime and (70, 90, and 120 l/s) in the Skimming Flow Regime. Results show that by increasing the flowrate in the stepped spillway the pressure on the bottom of the steps also increases. By adding reverse slope to the steps, the pressure increases on the bottom of the steps in comparison to the horizontal steps and steeper slopes cause higher pressures.

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