6th National Congress on Civil Engineering,
April 26-27, 2011, Semnan University, Semnan, Iran

Numerical Simulation of Uniform Flow Region over a Steeply Sloping Stepped Spillway

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Abstract

Stepped spillways have gained much interest in recent decades because of their compatibility with Roller Compacted Concrete (RCC) dams. Hydraulics of stepped spillways is not simple considering different flow regimes and regions along the chute. Estimation of flow characteristics on the stepped chutes is presently carried out by using some empirical formulae and physical modeling. However, this can be improved by application of Computational Fluid Dynamics (CFD) models. In this paper, flow characteristics within the uniform region of Javeh stepped spillway, located on the body of a RCC dam, was computed by a commercial CFD program. A comparison of the numerical and physical model results showed a relatively good agreement. The study indicates that the turbulence numerical simulation is an effective and useful method for the complex stepped spillway overflow.

Keywords: Hydraulic Structures, Stepped Spillways, Flow Characteristics, Numerical modelling, FLOW-3D

1. INTRODUCTION

Stepped spillways are found to be effective for energy dissipation of excess flood released from dams (e.g. Monksville & Upper Stillwater) [1,2]. Many studies [1,3,4] have shown that favorable design of stepped spillways can decrease the size of stilling basins significantly and thus saving on construction costs. Stepped spillways have gained much interest in recent decades because of their compatibility with Roller Compacted Concrete (RCC) dams [1]. Once a stepped chute is located on the body of a RCC dam, it offers additional constructional and economical advantages.

The flow over a stepped spillway can be classified into three types: nappe flow, transition flow and skimming flow [5]. On stepped chutes with skimming flow regime, the flow is highly turbulent. Once the outer edge of boundary layer reaches free surface, natural air entrainment commences (Figure1). Beyond this inception point, an air water mixture layer forms which gradually extends through the flow. Far downstream, flow will become quasi-uniform in a long chute and the depth will not vary at this equilibrium condition for a given flow [6]. L_u designates distance, along the chute, between the ogee crest and the section where quasi–uniform flow forms.

For skimming flow over the stepped spillway, energy dissipation occurs due to: i) recirculation between the main flow and the water trapped on the steps, ii) continuous production of large vortices and their break off and transport into the skimming stream [6]. If the flow reaches to uniform/quasi uniform flow condition, its characteristics can be readily used for estimation of energy loss over the stepped chute. On this basis a stilling basin is usually designed at the toe of the spillway for dissipation of the residual energy.

According to the conventional code of practice, designers calculate flow characteristics (i.e. velocity, depth and air concentration) over the stepped spillways by selecting some relationships among a variety of empirical formulae and design charts. These initial designs are further tested by physical models which are valuable but expensive and time consuming [3,4]. Nowadays, with the availability of high-performance computers and commercial CFD codes, flow characteristics over hydraulic structures can be quickly estimated by these numerical models which are highly needed for initial design purposes.