LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Influence of air concentration on rock scour development and block stability in plunge pools

PhD Candidate: Rafael Duarte

Thesis Directors: Prof. Anton Schleiss
Prof. Antonio Pinheiro

Thesis research under the IST-EPFL Joint Doctoral Initiative Funding by the Portuguese Foundation for Science and Technology (FCT) and EPFL

Introduction

In the design of hydraulic structures, exceeding incoming discharges are often released downstream by the creation of water jets. It might be the most suitable solution, especially in the case of high head dams or where chute spillways represent a high cost of construction. These jets impinge in the plunge pool and carry a large amount of energy, and its correct and safe dissipation is of crucial concern for hydraulic engineers.

Rock scour due to water jets is caused not only by the mean pressures applied on the water-rock interface, but is also influenced by its variations. Comprehensive experimental researches have been carried out with near-prototype jet velocities since 1998 by the Laboratory of Hydraulic Constructions of the Ecole Polytechnique Féderale de Lausanne (LCH-EPFL) and a physically-based method for scour prediction that considers fully transient pressures was proposed.

Although developments have been made to correctly describe rock scour development, the influence of the air concentration is still a question of debate. The ongoing research project aims at a comprehensive description of the dissipation of the air entrained by high-velocity jets in the plunge pool and its influence on the dynamic pressures on the pool bottom and inside rock fissures.

Methodology

The research methodology is composed by three main components. First, a theoretical study will be performed, to describe the physical processes and governing parameters concerning air entrainment and its influence on the pressures on the water-rock interface. Then, an experimental study on a generic model of prototype high-velocity jets will be undertaken to measure air concentration throughout different depths and radial distances in the shear layer of the impacting jet, in flat bottom and confined plunge pools. At last, a case study of a real case in reduced-scale model will be carried out for the analysis of real conditions of pool geometry and gate operation, with emphasis on the scale effects (Figure 1).

Experimental facility and instrumentation

A large experimental facility was conceived in the LCH-EPFL, capable of reproducing near-prototype high-velocity jets impinging on a plunge pool. The main part of the experimental set-up consists of:

A 3 m diameter cylindrical basin simulates the plunge pool. The water level in the pool is adjustable. A 63 m head pump provides the required energy for the jet, and a 72mm cylindrical nozzle models the jet.

The pool bottom simulates open 3D joints and is represented by two metallic components: a “measurement box”, that contains a cavity where a highly instrumented block, or “intelligent block” is inserted. The “intelligent block” has a cubic shape of 200 mm side. Between the “measurement box” and the “intelligent block”, a 3-dimensional fissure of 1 mm width is formed.

Passive aeration of the jets is obtained by the insertion of 6 aluminium tubes from where the outside air is dragged by the high-velocity jets flow inside the nozzle.

For the tests performed so far, the measurement system was composed by a hot-wire anemometer (type Testoterm Testo 491) to assess approaching air velocities and 12 kulite pressure transducers. The data acquisition device is a National Instruments (NI) card type USB-6259 series M driven with laboratory developed software.

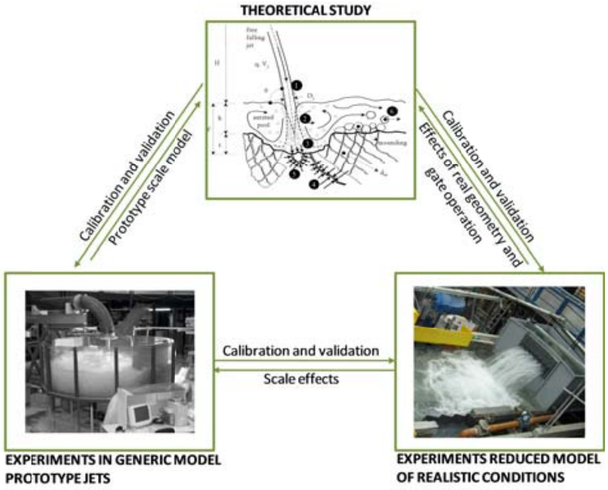

Figure 1: Research methodology composed by three components

Results

A preliminary set of experiments have been performed to assess dynamic pressures around a block positioned on the bottom of a plunge pool submitted to vertical high-velocity impinging water jets with and without passive air entrainment. The jet impingement position was in the center of the block, which was kept unable to move.

Figure 2 shows scaled plots of C_p and C_p' measured around the block, where red bars show tests without air and blue bars show tests with air. The typical behavior of these parameters is seen: On the pool bottom, (top of the block) both are maximum at stagnation, and decrease with radial distance from the jet axis. Then, in the fissures, both develop a quasi-constant behavior, at a value that is higher than the hydrostatic pressure. Values of C_p were higher for tests without air entrainment, in particular at stagnation and inside the fissures. Values of C_p' were higher for tests without air entrainment inside the fissures.

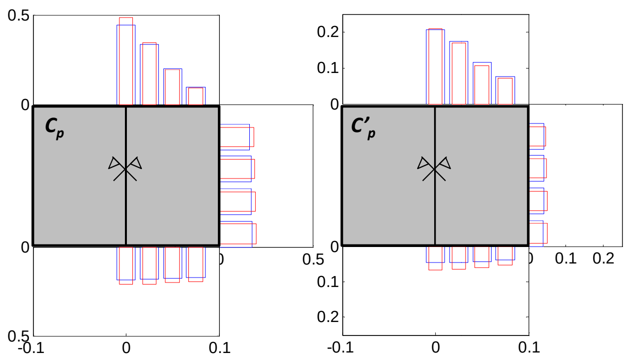

Figure 2 : Scaled plots of Cp and Cp' around the block. Y/Dj=11.11; Vj = 19.65m/s. Red: without air. Blue: with air.

Future developments will consider the measurement of void fraction, air bubble rate and chord length in different positions in the plunge pool, as well as the use of submerged jets for a better knowledge of the total entrained air.