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Experimental study of cavitation erosion around a surface-mounted semi-circular cylinder

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Abstract

The objective of this study is to investigate the collapsing behavior of cavitation, which leads to erosion. For this purpose, an experimental investigation was performed in a channel with a semi-circular cylinder obstacle at the Hydraulic Laboratory of ANDRITZ HYDRO in Vevey. Cavitation was achieved by employing a range of pressure differences over the test section. The obstacle promotes and localizes cavitation-induced erosion. The flow field behind the semi-circular cylinder was investigated as a characteristic example of bluff bodies, which exhibit a distinct separated vortex flow in their wake. A high-speed camera observed the cavitation behavior. At the same time, erosion tests were performed using paint (stencil ink). The intensity of cavitation is described by the cavitation number (σ), the lower the cavitation number, the higher the cavitation intensity. Three erosive cases at different cavitation numbers are presented here. The erosion (removal of paint) after 40-60 mins of operation revealed distinct and repeatable results. These results will serve as validation data for numerical studies. For a high cavitation number, a large number of Karman-vortex-like cavities are shed downstream of the obstacle. This results in a higher number of collapse events and ultimately more erosion. On the other hand, at lower cavitation numbers the erosion took place at the closure line of the cavity. We demonstrate that paint tests in combination with this geometry provide an efficient and economical way to investigate erosion patterns compared to expensive material loss tests.

Introduction

Cavitation is a phenomenon in which liquid converts to vapor due to the drop of local liquid pressure below the vapor pressure. The collapse of a vapor bubble or vapor cloud may induce a shock wave and a high-speed micro- jet, which can cause erosion (Van Terwisga et al 2009; Dular and Petkovšek 2015). This is a complex problem as it includes both material and hydrodynamic aspects.

Despite an extensive collection of experimental studies on cavitation is available, studies that would link cavitation to erosion are limited. The main reason is the lack of effective experimental techniques to capture very fast cavitation phenomenon together with very slow erosion phenomenon. Scale experiments are utilized for the risk assessment of probable erosive full-scale conditions and validation of numerical models (Van Rijsbergen et al 2012).

A range of measurements has been performed on a semi-circular cylinder in a high-speed erosion test rig to better understand the relationship between the physical phenomenon and potentially erosive impacts. A combination of two techniques have been employed: paint tests to investigate the various erosive patterns and high-speed video observations to record visual events such as cavitation collapse and rebound.

Experimental Setup

The ANDRITZ high-speed erosion test-rig has been used for the measurements. The flow in the setup is driven by a pump (KSB 6N89-858-233), which is installed approximately 2.5 m below the measurement section to avoid cavitation in the pump. A semi-circular cylinder obstacle is placed on a wedge in the measurement section to induce cavitation. An electromagnetic flowmeter (DN 100 from ABB) is used to measure the volumetric flow rate. The measurements from the downstream pressure transducer, the flowmeter, and the temperature sensor are used to determine the cavitation number σ. The cavitation number is given by: $\sigma=(p-p_v)/0.5\rho v^2$, where p is the downstream pressure, p_v is the vapor pressure, ρ is the density of the fluid and v is the free stream velocity of the flow at the throat of the wedge. The lower the cavitation number, the higher the cavitation intensity.

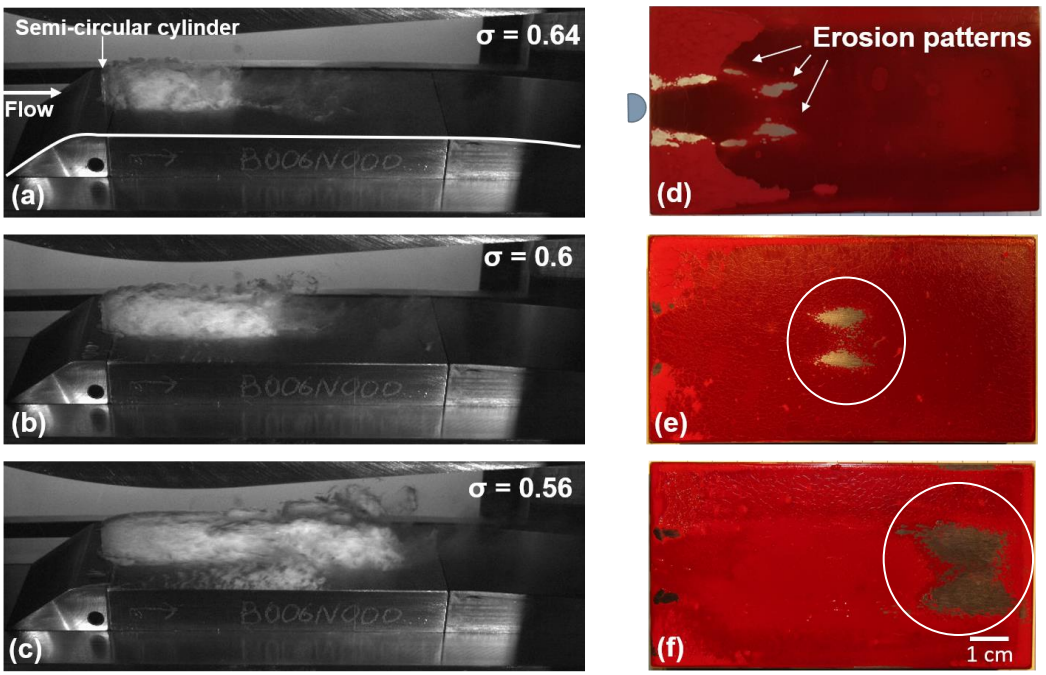

Figure 1: (Left) Video frames of cavitating flow behind the semi-circular cylinder. The flow is from left to right and light grey represents the cavitation region. (Right) Photographs representing the corresponding erosion patterns after 40-60 mins of operation.

A high-speed camera (Phantom v411) with a field of view of 640x232 pixels was used for imaging. A combination of two light sources from the front and an LED panel behind the measurement section were used to illuminate the cavity. The camera was placed at an angle of 32º to the horizontal to capture the cavity.

For the paint tests, red stencil ink was applied on the flat plate downstream of the cylinder - as thinly as possible with a syringe. The tests were conducted once the paint was dry (~24 hours of drying time). The results indicated the location of the most erosive cavitation implosions.

Results and Discussion

Cavitation was achieved by employing a range of pressure differences over the test section. The flow field behind the semi-circular cylinder was investigated as a characteristic example of bluff bodies, which exhibit a distinct separated vortex flow in their wake.

Three erosive cases at different cavitation numbers are shown in Figure 1 (a) – (c). The flow is from left to right and light grey represents the cavitation region. At lower cavitation number more intense cavitation can be seen. In Figure 1 (d) – (f), the erosion patterns (removal of paint) after 40-60 mins of operation can be seen for the corresponding cavitation numbers. At a high cavitation number, one would expect less erosion due to less intense cavitation as compared to the other two cases. However, a large number of Karman-vortex-like cavities are shed downstream of the obstacle. This results in a higher number of collapse events and ultimately more erosion (Figure 1 (d)). On the other hand, at the lower cavitation numbers (σ = 0.56, 0.6), most of the erosion took place at the closure line of the cavity (Figure 1 (e) and (f)). This is mainly because the vapor cavities are just shed at the closure line of the cavity, hence the collapse of vapor takes place in the same region but not upstream.

We demonstrate that paint tests in combination with this geometry provide an efficient and economical way to investigate erosion patterns compared to expensive material loss tests. These results will serve as validation data for numerical studies. Furthermore, numerical studies will enhance our understanding of the erosion mechanism.

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