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Dynamic Nonlinear Response of OWC Wave Energy Devices

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ABSTRACT

A two-dimensional numerical wave tank is used to compute the nonlinear radiation step response of oscillating water column wave-power plants. The influence of several parameters of the device such as front wall thickness and slopes, submerged aperture width and initial water height on the first three spatial modes of the chamber free-surface is investigated. Some interesting qualitative relations between the column response and these parameters are shown; their interest, and more generally the interest of using such simulation tools at the design stage of OWC wave-power devices, is highlighted.

INTRODUCTION

The design of oscillating water column (OWC) power plants requires the knowledge of their hydrodynamic characteristics, which are quantified by the dynamic response of the inner fluid volume to the excitation from the outer flow (diffraction) and the generation of waves outside by the pressure variation above the fluid column (radiation flow) (Evans, 1982). These characteristic response or transfer functions may be obtained either experimentally on scale models in wave basins (Sarmento and Brito-Melo, 1995), analytically for simplified geometry devices (Sarmento and Falcao, 1985), or numerically. The latter approaches are usually written in the general frame of linear free-surface potential flow theory. In such a case several assumptions are required, the major one being the condition of vanishing amplitude of the free-surface motions leading to the linearization of the boundary condition on its equilibrium (mean) position (*MWL* in Fig. 1). Thus, this kind of approach cannot take properly into account the nonlinear features of the hydrodynamic responses of these particular devices which may experience large amplitude motions of the inner free surface, even in standard operating conditions.

In this paper, we shall focus on the step radiation response of an OWC device, which describes the flow after releasing the inner free-surface from an out-of-equilibrium position corresponding to a nonatmospheric initial pressure in the chamber. A lot of computations were made using the software CANAL, a two-dimensional numerical wave tank developed in our Laboratory since 1988 (Clément and Mas, 1995). Some nonlinear phenomena are illustrated and quantified in relation with the main parameters defining the OWC plant: influence of the front wall shape, draught and thickness, influence of nonvertical chamber walls, nonlinearity with regard to the initial step magnitude, etc.

MATHEMATICAL FORMULATION

In all the subsequent equations the physical variables are nondimensionalized with regard to the water depth h for the length variables, and $(h/g)^{1/2}$ for the time variables. The fluid density is set to unity.

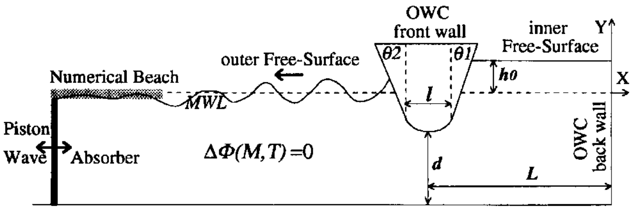

Fig. 1 Definition sketch

The usual assumptions of free-surface potential flow theory are made: The fluid is inviscid, surface tension is neglected, the atmospheric pressure above the outer free-surface is constant and taken as the pressure reference; in this particular case of radiation step response, the pressure above the inner free-surface is also equal to the atmospheric pressure for $T>0$; the flow is irrotational.

The water column width L was kept constant in the present study. Then, the OWC system is characterized herein by the 5 following parameters (Fig. 1): The angles θ_1 and θ_2 of the front wall with respect to the vertical; the width l of the front wall; its draught defined by the gap d between the sea bottom and the lower part (the lip) of the front wall; and the length L of the OWC chamber.

At $T = 0$, we start from a state of rest with an initial elevation h_0 of the free-surface in the OWC chamber, and we let the fluid evolve from this out-of-equilibrium position to the equilibrium where the inner free-surface is at the mean waterline position. Thus we simulate, in two dimensions and without simulating the pressure drop across the turbine, experiments similar to those made by Sarmento and Brito-Melo (1995) in 3 dimensions.

Owing to the above assumptions, the fluid velocity $\vec{V}$ derives from a scalar potential $\Phi(M,T)$ function of both time and space:

$$\vec{V}(X,Y,T) = \vec{\nabla}\Phi(X,Y,T) \tag{1}$$

It is easy to show that the potential function is the real solution of the following nonlinear initial boundary value problem:

$$\Delta\Phi(X,Y,T) = 0 \quad \text{in the fluid domain} \tag{2}$$

$$\frac{\partial\Phi}{\partial X}(0,Y,T) = 0 \quad \text{on the OWC back wall} \tag{3}$$

$$\frac{\partial\Phi}{\partial Y}(X,-1,T) = 0 \quad \text{on the sea bottom} \tag{4}$$

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KEY WORDS: Hydrodynamics, free surface, oscillating water column, numerical wave tank.