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Absorption of Outgoing Waves in a Numerical Wave Tank Using a Self-Adaptive Boundary Condition

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ABSTRACT

An absorbing boundary condition for time-domain Numerical Wave Tanks (NWT) is developed from a previous study related to active physical absorbers for a wave basin. The starting point is the same: The optimal (ideal) time domain absorption condition for a moving piston is expressed as convolution products of the velocity by the hydrodynamic force on the moving piston. The present extension to fixed boundaries of the numerical fluid domain is based on the approximation of the convolution kernels by exponential series expansions. This is achieved by using Prony's method, which is detailed in the Appendix. The time-domain absorption condition is then expressed as a set of ordinary differential equations which can be easily and naturally appended to the initial ODEs set of the NWT algorithm. The coefficients of the new ODE for a piston-like condition are given. In order to improve absorption efficiency, some of these coefficients are continuously varied during the simulation, according to the output of a Kalman filter scanning the instantaneous frequency of the force signal. For this reason the method is said to be self-adaptive. This results in very high absorption coefficients in a broad range of wave frequency.

INTRODUCTION

The time-domain simulation of wave generation and propagation in a numerical wave tank over a long period requires a good absorption technique at one end (or both ends) of the tank, in order to avoid spurious reflections in the computational domain. The problem also occurs in physical wave tanks, and a lot of research has been undertaken in the past decade to develop active (called dynamic) wave absorbers. Among them, an active piston wave absorber was developed and tested numerically in a linear wave tank by Chatry et al. (1998). The technique initially developed for physical wave absorbing devices was further extended (Chatry et al., 1999) to the control of wave power plants of the oscillating water column (OWC) kind.

The underlying idea of the present work is that the numerical simulation of a good physical wave-absorber, when realizable, should provide a good numerical absorber. We shall see how the above cited self-adaptive strategy can be extended to devise a new absorbing boundary condition for the fixed vertical end of nonlinear NWTs. The low frequency piston mode proposed by Clément (1996) was a particular case, at zero frequency, of the ideal absorption relation presented here. It has been improved in order to take into account the effect of the recent past of the flow in the vicinity of the boundary. It is important to consider that we are working in the time domain. Thus, it is well known that a lot of useful results can be easily derived by Fourier transforming their counterpart in the frequency domain. If we consider the problem of wave absorption at a vertical boundary of a numerical basin, it is well established, in the linear frequency domain approach, that the Sommerfeld condition stating that $\partial \Phi / \partial t = c(\omega) \partial \Phi / \partial n$ provides a simple and efficient damping of outgoing waves. In this simple scalar relation, $c(\omega)$ is the real phase velocity of the (monochromatic) waves. The formal transposition of this relation to the time domain unavoidably leads to a convolution product of the Fourier transform of RHS terms. These convolution integrals, as those we will deal with in this paper, reflect the effect of the history of the flow at the current time t. They are not local in time, and this is the major difficulty of the absorption problem in the time domain. Some authors propose to use the so-called Orlanski's relation ($\partial \Phi / \partial t = c(t) \partial \Phi / \partial n$) (Orlanski, 1976), which is nothing but the simple transposition of Sommerfeld's relation to the time domain term by term. From the above argument it is easy to realize that the absorption would not be correct in the time domain, except when applied to some special cases as a monochromatic wave train, where Orlanski's relation simplifies into Sommerfeld's relation, or for long waves where the coefficient no longer varies and keeps its asymptotic value $c \equiv 1$. Our goal here was to devise an efficient time-domain absorption condition working blindly with any kind of broad-banded, time-varying incident wave train.

MATHEMATICAL FORMULATION

Velocity Potential Problem

The usual assumptions of potential flow theory are made, namely: inviscid fluid, irrotational flow, no surface tension. All the variables will be nondimensionalized using the (constant) water depth h as the reference length and $\sqrt{h/g}$ as the reference time, g being the gravity acceleration. The fluid density is arbi-

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KEY WORDS: Numerical wave tank, wave absorption, absorption condition, potential flow, Kalman filter, Prony's method.