Nonlinear Hydrodynamic Effects of Opposing Jet-Current on Waves

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ABSTRACT

In the paper the modifications of a wave field due to a non-linear interaction with an opposing jet-current are analysed. Hydrodynamic governing relations are represented by the mass conservation and 2DH momentum equations. Wave refraction is obtained by the irrotationality of wave number, the energy conservation and Doppler effect equations. A numerical solution, based on a "two-level iteration" method, is proposed and some applicative examples are also reported.

KEY WORDS: current-wave; jet; wave-refraction; numerical model; non-linear interaction; hydrodynamics

INTRODUCTION

The influence of a current on wave motion is a very common physical phenomenon, characterised by the generation of geometric and kinematic modifications of the flow field (such as wave front deformation, wave height and length reduction or increase, tidal current development etc.).

In coastal areas this subject assumes considerable interest in the examination of the effects of an opposing jet-current on waves. This situation can be, in fact, the basic scheme of some important technical applications (e.g. controlled sea discharges from plants or sewage outlets, natural discharges, river mouths etc.).

The hydrodynamic study of this problem has been treated by several researchers with mathematical models, where some appropriately simplified schemes are considered. A good synthesis of these researches is reported by Peregrine (1976) and Jonsson (1990).

Ismail (1981) and Ismail and Wiegel (1983) treated the problem analytically, evaluating only the spreading of a surface jet due to an opposing wave and also reported some experimental results. This aspect is very interesting because the laboratory studies on the subject request large experimental facilities (wave basin).

More recently, Yoon (1987) and then Yoon and Liu (1989) studied the problem considering only the long waves (e.g. tidal flows near an inlet or estuary entrance). By applying the parabolic approximation criterion, the Authors obtained a particular linearised expression of the Boussinesq equations. In the subsequent numerical applications, Yoon and Liu (1990) introduced another simplification, which consists in ignoring some dissipative turbulent terms but, especially, in evaluating the wave number, \(k\), from the dispersion relation without current; i.e. the modifications due to non linear jet-wave interaction were neglected.

In the first part of the present work, hydrodynamic analysis of the non linear effects of an opposing jet-current on waves is presented. In particular, even if several simplified hypotheses are made (regular waves expressed by a Stokes 2-order theory, absence of reflection and breaking wave), no physical aspects of the jet-waves interaction are overlooked. In the second part a numerical solution model of the governing equations is presented, which allows us to evaluate both the characteristics (time-averaged) of the flow field and those due to the geometric transformation of wave opposing fronts (wave height and length values).

The numerical model is able to be applied in an arbitrary wave direction and a generic configuration of the sea bottom (the only limitation is the hypothesis of mild slope).

Several examples are reported to show the numerical results in some particular cases.

GOVERNING EQUATIONS

Regarding the scheme outlined in Fig. 1, the flow field and refraction equations are as follows:

a) flow field equations

The flow field is described by continuity and momentum equations. In particular the description is realised by a 2DH simplified model, where the vertical velocity component is neglected (shallow water hypothesis), while for the horizontal velocity components, \(u\) and \(v\), the depth-averaged and the time-averaged (in the period \(T\) values, \(U\) and \(V\), are considered.

Employing these hypotheses and ignoring the viscous stress, the governing system is (Dalrymple, 1980; Arcilla and Lemos, 1990):