

The Regularity and Local Bifurcation of Steady Periodic Water Waves

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Abstract

Steady periodic water waves on infinite depth, satisfying exactly the kinematic and dynamic boundary conditions on the free surface, with or without surface tension, are given by solutions of a rather tidy nonlinear pseudo-differential operator equation for a 2π -periodic function of a real variable. Being an Euler-Lagrange equation, this formulation has the advantage of gradient structure, but is complicated by the fact that it involves a non-local operator, namely the Hilbert transform, and is quasi-linear.

This paper is a mathematical study of the equation in question. First it is shown that its $W^{1,2}$ -solutions are real-analytic. Then bifurcation theory for gradient operators is used to prove the existence of (non-zero) small amplitude waves near every eigenvalue (irrespective of multiplicity) of the linearised problem. Finally it is shown that when surface tension is absent there are no sub-harmonic bifurcations or turning points at the outset of the branches of Stokes waves which bifurcate from the trivial solution.

1. Introduction

The periodic water-wave problem for steady irrotational free surface flows in the presence of gravity, with or without surface tension, can be formulated as a problem for a 2π -periodic solutions w of the equation

$$\mu C w' = w + w C w' + C(w w') - \beta \left\{ \frac{w'}{\sqrt{w'^2 + (1 + C w')^2}} \right\}' + \beta C \left\{ \frac{1 + C w'}{\sqrt{w'^2 + (1 + C w')^2}} \right\}'. \quad (1.1)$$

Here C denotes the periodic Hilbert transform (also known as the conjugation operator in the theory of Fourier series [38]), $'$ is differentiation, and

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