

The Regularity and Local Bifurcation of Steady Periodic Water Waves

B. BUFFONI, E. N. DANCER, J. F. TOLAND

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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angle 2θ between them Denoting by μ gL/c^2 the dimensionless bifurcation parameter L is the wave length along the direction of the travelling wave and c is the velocity of the wave bifurcation occurs for $\mu \cos \theta$ For non resonant cases we first give a large family of formal three dimensional gravity travelling waves in the form of an expansion in powers of the amplitudes of two basic travelling waves Diamond waves are a particular case of such waves when they are symmetric with respect to the direction of propagation The main object of the paper is the proof of existence of such symmetric waves having the above mentioned asymptotic expansion Due to the occurrence of small divisors the main difficulty is the inversion of the linearized operator at a non trivial point for applying the Nash Moser theorem This operator is the sum of a second order differentiation along a certain direction and an integro differential operator of first order both depending periodically of coordinates It is shown that for almost all angles θ the 3 dimensional travelling waves bifurcate for a set of good values of the bifurcation parameter having asymptotically a full measure near the bifurcation curve in the parameter plane θ, μ

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