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Long waves propagating over a circular bowl pit

Kyung-Duck Suh[a, *], Tae-Hwa Jung[a], Merrick C. Haller[b]

[a] *School of Civil, Urban, and Geosystem Engineering, Seoul National University, San 56-1, Shinlim-Dong, Gwanak-Gu, Seoul 151-742, Republic of Korea*
[b] *Department of Civil, Construction, and Environmental Engineering, Oregon State University, 202 Apperson Hall, Corvallis, OR 97331-2302, USA*

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Abstract

An analytic solution to the mild slope wave equation is derived for long waves propagating over a circular, bowl-shaped pit located in an otherwise constant depth region. The analytic solution is shown to reduce to a previously derived analytic solution for the case of a bowl-shaped enclosed basin and to agree well with a numerical solution of the hyperbolic mild-slope equations. The effects of the pit dimensions on wave scattering are discussed based on the analytic solution. This analytic solution can also be applied to pits of different general shapes. Finally, wave attenuation in the region over the pit is discussed.

Keywords: Long waves; Analytic solution; Mild slope wave equation; Bowl pit

1. Introduction

As surface gravity waves propagate from the deep ocean to the coast, they are transformed continuously by shoaling, refraction, diffraction, and reflection until they break and dissipate. Numerous numerical models have been developed that include the above phenomena and predict the transformation of waves. However, since numerical solution techniques inherently involve approximations, it is necessary to test these models against both analytic solutions and laboratory and field data from representative cases. In theory, the most rigorous test cases would involve comparisons with laboratory and field data, because they are the physical systems of interest. However, such comparisons can be problematic, since it is difficult to measure all the necessary boundary and forcing conditions, especially in field experiments. Comprehensive measurements are somewhat easier to obtain (and repeat) in a

* Corresponding author. Tel. : +82 2 880 8760; fax: +82 2 887 0349.
E-mail addresses: kdsuh@snu.ac.kr (K.-D. Suh), togye176@snu.ac.kr (T.-H. Jung), hallerm@engr.orst.edu (M.C. Haller).

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laboratory setting, yet difficulties arise when trying to reproduce the laboratory wave generating and absorbing systems in numerical models. Also, experimental data always contain a certain amount of measurement errors.

Analytic solutions are another avenue for testing numerical models. While comparisons with physical data are a good test of whether the physics of the model are complete, comparisons with analytic solutions are a direct test of the numerical model scheme under idealized conditions. These comparisons are also useful for model development, and an advantage of analytic solutions is that they are generally developed at reduced cost, time, and labor in comparison to experiments. In addition, it is often simpler to use the analytic solution as a basis for evaluating the influence of specific forcing or boundary conditions on the problem. Nonetheless, most wave transformation problems are complex, and analytic solutions are available for only special situations.

A frequently considered problem in analytic studies of long wave transformation is the long wave motion around a circular island mounted on an axi-symmetric shoal. Homma [4], Vastano and Reid [13], Jonsson et al. [5], and Zhu and Zhang [16] studied long waves around a circular island mounted on a parabolic or conical shoal. Also, Zhang and Zhu [15] and Fujima et al. [2] presented the solution around a conical island or over a parabolic shoal. Recently, Yu and Zhang [14] presented a more general solution by describing the radial topography of the shoal by a power of the radial distance.

In contrast, the present analytic study considers long waves propagating over a circular, bowl-shaped pit located in an otherwise constant depth region. In addition to providing an analytic solution for use in verifying numerical wave models, this new solution can be used to further study wave transformation over a bowl pit. Such a process is of practical interest, for example, in the analysis of shoreline response in the lee of bathymetric anomalies created by the dredging of nearshore sands (see Michalsen et al. [10] and references therein). In the following section, we derive an analytic solution to the mild slope wave equation for long waves propagating over a circular bowl pit. The analytic solution is then compared with a previously derived analytic solution for a related bottom geometry, and a numerical solution based on the hyperbolic form of the mild slope equation. We also discuss the effects of the pit dimensions on the wave scattering using our analytic solution. Finally, wave attenuation in the region over the pit is discussed, and then we summarize the main conclusions.

2. Analytic solution

Consider an axi-symmetric bowl-shaped pit situated in an otherwise constant depth region as shown in Fig. 1, where the origin of the horizontal coordinate system is taken to be the center of the pit, r is the radial distance from the origin, and θ is the angle measured counterclockwise from the positive x-axis. The incident wave is assumed to be a long-crested wave propagating in the positive x direction. The water depths at the origin and in the constant

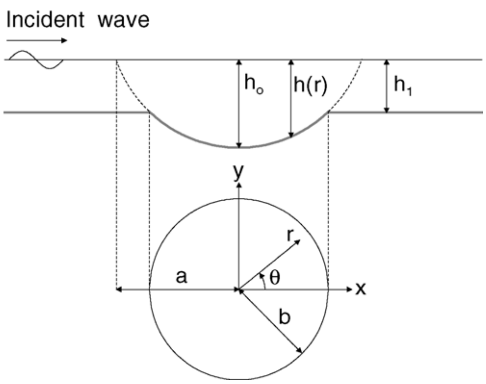

Fig. 1. Definition sketch of a circular bowl pit located in an otherwise constant depth region.