

Characteristics of Vortex Structure Induced by a Solitary Wave Propagating over a Rectangular Cavity

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ABSTRACT

The vortex structure induced by a solitary wave propagating over a rectangular cavity is studied experimentally, using the particle image velocimetry (PIV) and flow visualization technique. The aspect ratio of the cavity (the ratio of length to depth of a cavity, G/D) ranges from 0.33 to infinity in the study. The ratio of wave height (H) to water depth (D) in the experiment is 0.2. The vortex shedding process was identified particularly for $G/D = 1.0$. Detailed vortical structures in the case were observed using flow visualization technique – particle trajectory photography. The quantitative characteristics of shedding primary vortex in the cavity, such as the trajectories of the vortex core, vorticity of the primary vortex core, and the circulation of the primary vortex, are discussed in detail.

KEY WORDS: wave-cavity interaction; solitary waves; flow visualization; particle image velocimetry.

INTRODUCTION

The propagation of water waves over a submerged obstacle has received much attention in the decades. In the physical applications, it related not only to coastal and ocean engineering problems, but also to the sustainable development for near-shore environment. A submerged obstacle can be regarded as a submerged dike used to prevent erosion of the coast caused by surging waves. To have a better understanding of the complex flow field generated by wave-obstacle interaction, many researchers used rectangular shape to simplify the geometry of the submerged dike.

Besides surging waves, there is a natural disaster ‘tsunami’ which has tremendous energy, and it causes huge damage in the near shore region. On December 26, 2004, an earthquake of intensity 8.9 on the Richter scale located near the Island of Sumatra generated a tsunami which severely impacted the shores of the Indian Ocean, particularly from Indonesia to Sri Lanka. The tsunami that washed away reaches of the coast. In the disaster, the base of American Navy in the Indian Ocean, Diego Garcia, was not damaged by the tsunami. The reason may be attributed to the coral reef near the base, and the existence of the trench ‘Chagos’ which is 5,400 km deep, 740 m long outside of the coral reef. Coral reef and Chagos trench act as an obstruction decreasing the

energy of the tsunami. Hence, a tsunami propagating over a trench is an interesting topic to be further investigated.

Many studies concerning the interaction between a solitary wave and uneven bottom, Madsen and Mei (1969) solved long wave equation in shallow water and compared the numerical result with experimental data. They analyzed wave deformation as a solitary wave propagates over a mild slope and found a single solitary wave separates to a series of waves having small amplitudes. Goring and Raichlen (1990) studied reflection and transmission of an incident solitary wave propagating over a continental shelf, using both numerical and experimental method. They found that non-linear KdV equation is better to be used in the conditions of larger water depth and wave height.

Some researchers considered the phenomenon of a solitary wave propagating over a submerged obstacle, and investigated on vortex shedding process attributed to the interaction. Rey et al. (1992) discovered vortex shedding process in the vicinity of submerged dike due to flow separation induced by a the interaction. Ting and Kim (1994) measured velocity distribution around a submerged dike, and observed the corresponding characteristics such as vortex strength. Losada et al. (1989) discussed the wave deformation while a solitary wave propagates over a rectangular dike using KdV equation. Losada et al. (1995 and 1997) measured the harmonic evolution of an monochromatic wave as they propagate over a porous dike under non-breaking conditions.

Zhuang and Lee (1996) developed a viscous rotational model (vorticity equation) from Navier-Stokes equation to calculate the flow pattern in the lee side of a submerged rectangular dike while a solitary wave propagates over it. Tang and Chang (1998), Huang and Dong (1999 and 2001) studied the interaction between a solitary wave and a submerged dike using a numerical water flume. They used Navier-Stokes equation and free surface boundary condition to analyze the deformation of the wave profile, and it can be used to analyze vortex shedding process in the vicinity of a dike.

Chang et al. (2001) have been the first using PIV to measure the velocity distribution in the vicinity of a rectangular dike while a solitary wave passes through. The authors compared the data with those calculated by Reynolds Averaged Navier-Stokes (RANS) model. Chang (2004) investigated vortex shedding process induced by a solitary wave propagating over a submerged rectangular dike using PIV, laser induced fluorescence (LIF) technique, and particle trajectory photography. Many vortices were found in the study, and a vertical jet