ABSTRACT
A nonlinear wave transformation model which can calculate the distribution of wave height inside a harbor with good accuracy has been used to estimate harbor tranquility. In a conventional procedure, however, the characteristics of such calculation could not be applied enough because the variation of wave height ratio with the steepness of incident waves would be ignored in prediction of an occurrence probability of wave height inside a harbor from one of offshore waves. In this paper, an appropriate procedure of harbor tranquility analysis for using a Boussinesq-type wave transformation model is proposed and its applicability is demonstrated in a harbor on coral reef topography.

KEY WORDS: Harbor tranquility; coral reef; nonlinear wave transformation; Boussinesq model.

INTRODUCTION
Goda (2010) has mentioned that the fundamental function of a harbor is to provide safe anchorage for vessels and to facilitate smooth and unhindered transfer of passengers and cargo between vessels and land. Considering that, it is normally expected that the motion of vessels moored at anchorage or along a wharf should be limited even in a storm condition by the guaranteed harbor tranquility. Thus, both the design of harbor layout and the improvement of port facilities are carried out by many researchers and engineers to reduce the wave height in a wharf.

On the other hand, the allowable movements of moored ships for cargo handling were suggested (e.g. Bruum, 1980; Ueda and Shiraishi, 1988; PIANC, 1995), and they were related to the critical wave heights with the analysis of moored ship motions for wave actions (e.g. Ueda et. al., 1994). Thus, the judgment of harbor tranquility can be done with the estimation of wave height distribution inside a harbor.

Such concept of harbor calmness is mentioned in the “Technical Standard and Commentaries for Port and Harbour Facilities in Japan” (OCDI, 2009). And then, a conventional harbor tranquility analysis method, which is introduced by Goda (2010), has been applied to evaluate a cargo handling operation rate at each berth in a harbor. In this method, the distribution of wave height inside the harbor is usually estimated with a linear wave transformation model, considering both the wave diffraction around breakwaters and the wave reflection on seawalls, assuming a flat bathymetry of harbor inside.

Recently, many kinds of the nonlinear wave transformation model, e.g. Boussinesq-type, have been widely employed to estimate wave field in shallow water. The NOWT-PARI (Nonlinear Wave Transformation model by Port and Airport Research Institute) produced by Hirayama (2002) in order to simulate the wave transformation in the harbor and coastal area in random seas is one of them.

This model is based on the improved Boussinesq equation derived by Madsen and Sørensen (1992) with the dispersion enhancement coefficient; \( B = 1/15 \). Thus, both the weak-nonlinear wave shoaling and the wave dispersion closely corresponding with the linear wave theory can be reproduced. On the other hand, the wave diffraction, reflection and transmission should be calculated because a harbor is usually protected with some breakwaters and seawalls with or without wave dissipating works, and the wave refraction, shoaling and breaking should be calculated because a coast is usually connected to slopes and shoals. To do those, the several boundary techniques, i.e. the sponge or porous layer for open and partial reflection boundary (Hirayama, 2002, 2009; Hirayama and Hiraishi, 2003), the wave breaking and run-up model (Hirayama and Hiraishi, 2005), the wave overtopping model (Hirayama and Hasegawa, 2011) and so on, have been developed and installed to the NOWT-PARI. Moreover, multi-directional irregular waves are generated at the incident boundary in the same way as in a serpent-type multi-directional irregular wave maker with absorbing the reflected waves (Hirayama, 2002).

Nowadays, the NOWT-PARI has been already widely used to estimate a harbor tranquility in Japan. In a conventional procedure, however, the benefits of its calculation accuracy could not be applied enough because the variation of wave height ratio with the steepness of incident waves would be ignored in prediction of an occurrence probability of wave height inside a harbor from one of offshore waves. Therefore, it is required to develop an appropriate harbor tranquility analysis method for making the best use of such nonlinear wave transformation model.

In this paper, at first, the calculation accuracy of the NOWT-PARI for nonlinear wave transformation inside a harbor on coral reef topography is verified by comparison between the calculated and observed wave heights and spectra. Next, an appropriate procedure of harbor tranquility analysis for using such nonlinear wave transformation model is proposed. Then finally, its applicability is demonstrated with the