論文の内容の要旨
Abstract of Dissertation

論文題目　Modeling Waves and Currents around Submerged Breakwaters and over Complex Bathymetries
(潜堤周辺および複雑な地形における波と流れのモデリング)

氏　名　ラナシンヘ ロシャン スミンダ
Name of Author

(本文) (Abstract)

Many coastal regions are suffering serious erosion due to sea level rise, the reduction of sediment supply from rivers and the interruption of alongshore sediment transport by man-made structures such as groynes. In that sense protection of coast against erosion is considered to be a challenging task in coastal engineering. In general coastal protection schemes are classified into 1) direct measures, which confronts the problem by preventing or amending the immediate effects of the problem (*e.g*. protective structures, artificial nourishment etc.), and 2) indirect measures, which take away the cause of the problem (preventing sand mining, coral mining etc.).

However sand mining and coral mining (for limestone) cannot be prevented completely (only controllable), as they are highly demanded construction materials for various projects. Direct measures, which include various kinds of coastal structures, *e.g.*, offshore breakwaters, groynes, artificial headlands, have been utilized for beach erosion control, but there is strong negative public reaction to these hard structures and rock emplacement (sea wall type) along coasts other than artificial nourishment. This leads uncertainty to local government authorities about how to treat shoreline erosion. Some are resorting to "Planned Retreat", where houses and other properties are simply removed and the coast is left to erode by allowing nature to dominate. However planned retreat can be expensive, unnecessary, and most probably impossible especially in highly modified environments.

Submerged breakwaters are becoming increasingly popular as they offer number of aesthetic advantages over the other shore protection structures. At the same time these structures only provide partial barrier to the sediment fluxes, which means designers have more control in designing a desired coastal response. On the other hand, water exchange around submerged breakwaters is considered to be better than that of their emergent counterpart; therefore it is advantageous for surrounding marine environments making an environmentally friendly solution to the beach protection.

However the utilization of submerged breakwaters for shore protection is relatively new; hence proper design guidelines are yet to be established. Though there are a few studies on submerged breakwaters on laboratory scale and prototype scale at present, most of them focus on wave transformation and very little is known about the evolution of nearshore currents in the vicinity of these structures, which is important for predicting morphological changes around them.

With the objectives of further investigating the physical mechanism of generation of currents around submerged structures, a series of laboratory experiments were conducted in the wave basin using normal incident regular waves. The laboratory experiments conducted with three submerged breakwater system and infinite number of breakwater system revealed that the strength of the converging circulation currents behind submerged breakwaters is highly sensitive to the wave period. At the same time strength of these circulation currents showed dependency on the number of breakwaters and the gap between two adjacent breakwaters. However converging circulations were observed only in few cases with three submerged breakwater systems indicating limited range for application under the tested wave condition. Laboratory experiments further revealed that the converging circulations tend to be weakened or completely disappear at a particular gap width, when the return flow through the gap attains its maximum. This feature was more noticeable in infinite number of breakwater system. It should be noted that in designs this hazardous gap width to be avoided.

The highly nonlinear profile of the waves and strong shoreward mass flux over submerged breakwaters make it difficult to describe the hydrodynamic characteristics around them even in a qualitative manner. Certain fractions of waves are reflected at the offshoreward face of the structure depending on the freeboard and interact with the incident waves creating partial standing waves. Moreover, under small freeboards, submerged breakwaters are subjected to wetting and drying coexisting fields. In order to simulate the complex hydrodynamic characteristics mentioned and explained above, a time-dependent, nonlinear dispersive wave model is the most straightforward approach; hence some efforts have been made to discuss the evolution of waves and currents around submerged breakwaters by applying two numerical models based on a modified version of Nwogu (1993) Boussinesq-type equations for waves and currents over impermeable beds and a truncated version of Chen (2006) Boussinesq-type equations for waves and currents over porous beds.

The Boussinesq-type model equations for studying waves and currents around coastal structures have made remarkable advance during the past few decades. However, contrast to the fast development in modeling of hydrodynamics around impermeable structures, that of porous bottom or porous structures have been very slow, inevitably due to the uncertainty on determination of a few empirical coefficients associated with porous media. Most of the coastal structures such as groynes, seawalls and offshore breakwaters are constructed with rubble, rocks or concrete blocks to withstand the forces generated by breaking waves and provide sufficient dissipation by turbulence in the interstices. As submerged breakwaters result primarily in wave dissipation through wave breaking over the structure, bottom friction and turbulence in porous layer, it is essential to include porous damping in modeling waves and currents around these structures. In the latter model, the equations of motion for porous medium include an empirical Forchheimer-type term for laminar and turbulent frictional losses and an inertial term for acceleration effects following Sollitt and Cross (1972) and the former model can be easily recovered by setting flow velocities in porous media equal to zero.

Following Kennedy et al. (2000), an eddy viscosity type of formulation is used to simulate energy dissipation due to breaking and the rate of wave energy dissipation is expected to be governed by the magnitude of the eddy viscosity, which is related to the turbulent kinetic energy, and a turbulent length scale. The turbulent kinetic energy is determined from a semi-empirical transport equation with a source term for turbulent kinetic energy production by wave breaking. The moving shoreline is simulated with either Madsen (1997) or Kennedy et al. (2000) slot technique and the same technique is utilized to overcome any instability when the submerged breakwaters are under wetting and drying coexisting field (only for impermeable breakwaters). Considering the impermeable submerged breakwaters are structures with finite porosity, the model does not require any special treatment at the boundary of the wet and dry area.

A new artificial energy dissipation term is introduced to overcome unrealistic flow patterns that lead to numerical instabilities near abrupt depth configurations, as it could be observed at the offshore face or the onshore face of submerged breakwater. This follows the physical phenomenon of energy dissipation in pipe flows, when there exists a sudden expansion of a pipe diameter.

In the process of developing the two dimensional wave-current model and improving the nearshore current field, the anisotropic eddy viscosity coefficients were introduced following Tajima et al. (2007). Traditionally the eddy viscosity coefficients are set to be isotropic in most of the wave breaking induced energy dissipation sub-models; however as Tajima et al. (2007) have discussed, the eddy viscosity features should not be significant in the direction of wave crest compared to those in the direction of wave propagation.

Numerical simulations carried out with a production term proposed by Nwogu (1996) in turbulent kinetic energy equation showed excellent agreement with the laboratory experimental data obtained from wave-current flume. The mixing length, which is the most important free parameter governing the turbulent structure, needed to be calibrated depending on the wave environment and bottom configuration used to get better agreement with experimental data. The mixing length had to be kept around three times the deep water wave height when simulating one dimensional horizontal wave transformation over monotonic slope, whereas it had to be brought down to around deep water wave height, when simulating wave transformation over submerged breakwaters, which can be explained with respect to the major type of breaking involved. However in two-dimensional horizontal wave propagation, Nwogu (1996) type production term failed to reproduce the turbulence structure appropriately and failed to simulate the hydrodynamics around submerged breakwaters even in a qualitative manner. Moreover this type of model is unable to introduce production of turbulent kinetic energy to the closure model locally due to the dependency on the eddy viscosity. Further improvements were made to the production term by removing dependency on eddy viscosity by assuming local balance between production and dissipation of turbulent kinetic energy at equilibrium. The comparison between simulated results with the new model show qualitatively good agreement for evolution of waves and currents in horizontal two-dimensional wave propagation, if the breaking induced energy dissipation sub-model is properly calibrated and if appropriate values for the empirical coefficients are chosen for porous media.

Lastly, the predictive skills of the two-dimensional horizontal model based on Nwogu (1993) equations were investigated on the evolution of waves and currents over complex bathymetries. The model is utilized to simulate the hydrodynamic features in Shimoniikawa coast, which is located in Toyama bay under giant swells called "Yorimawari Waves. Numerical simulations were successfully carried at three sites namely Tanaka, Ashizaki and Ikuji and the damage mechanisms in Ashizaki and Ikuji were further confirmed with these numerical simulations.