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Recent Research and Development of Numerical Wave Tanks — A Review

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ABSTRACT

This paper presents a review of recent progress of numerical wave tank (NWT) research and development. A wide variety of 2-D and 3-D NWT have been developed for simulating wave, diffraction, radiation, floating body motion and other related topics. The review focuses on the development of NWT similar to experimental wave tanks (EWT). Although the viscous flow NWT is equally as important as the ideal fluid NWT, the present review is centered on the latter. It includes typical formulations, numerical implementations, methods of wave generation and wave damping and absorbing, wave-wave interaction, diffraction, radiation and floating body motion. A comment on the viscous flow NWT is given in the concluding remarks.

INTRODUCTION

Engineers and designers are commonly faced with problems of fluid/structure interaction, not only in naval architecture and ocean engineering, but also in various other industrial fields, such as car design, aeronautics, spacecraft design, internal combustion engines, turbo-machinery, etc. To increase the performance of their products, they generally resort to simulation on models to validate their solutions before bringing their project to the production stage. Depending on the kind of problem being considered, the choice may be open between physical models or numerical models. Historically, there were not many choices left and the former experimental approach was obviously the only solution to visualize the fluid flowing around bodies. In aeronautics, for instance, wind tunnels were systematically used for the design of aircraft till the Sixties, and the knowledge of the phenomena involved was essentially acquired through experiments. The equivalent of a wind tunnel in naval and offshore applications is the wave basin or the towing tank.

As in the case of aeronautics where computer codes have progressively replaced the wind tunnels, researchers are developing numerical wave tanks (NWT) intended to reproduce as closely as possible the flow around marine structures like ship or offshore rigs as they are excited by ocean waves and currents. For historical and technical reasons, these computer codes are less advanced in hydrodynamics than they are in aerodynamics. The presence of the moving free surface, which adds one complexity level to the air/body interaction problem, is in large part responsible for this.

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In the design and analysis of marine structures, the random wave loading is usually assumed to be a Gaussian process and the response of the structure is assumed to be linear. These assumptions assure designers they will obtain simple and complete response characteristics of the system through spectral analysis. However, the above assumptions remain valid as long as the waves are not very rough (Hs = 4 to 6 m). The recent 2nd-order nonlinear diffraction theory with the aid of the Volterra model for the 2nd-order wave force may be valid for the high seas (Hs = 6 to 9 m), though it remains to be extensively investigated before coming to a conclusion. Very high seas (Hs = 9 to 14 m) and phenomenal seas (Hs = over 14 m) usually contain nonlinear components higher than 5th-order. Thus, the design estimates based on the linear and 2nd-order theory need to be modified by a factor of safety to compensate for the unknown higher-order nonlinear wave effects. As these modifications still cannot ensure final safety, one resorts to conducting the model test in EWT. It is believed that the nonlinear forces will eventually be simulated in NWT.

Many nonlinear hydrodynamic problems were usually observed in EWT during the industry design work. MARINTEK found ringing phenomena on the Heidrun TLP during the experiment in a wave tank. Ringing is a dramatic transient stage or burst in a steady state springing signal (Natvig, 1994). The bursting tendon vibration was due to the impact of waves that were asymmetric about the vertical axis (Davies et al., 1994). The nonlinear hydrodynamic problems in ship motions were usually investigated by comparing the linear ship motion theory with the model tests in EWT. Green water shipping is a highly nonlinear and enormously difficult problem due to the breaking of waves in both EWT and NWT. The bow submergence of the destroyer model was highly overpredicted by linear theory with the Gaussian sea assumption. A ship capsizing in a roll had been studied in both theory and experiment, mainly looking at the effect of the nonlinear restoring moment with a negative metacentric height. The effect of a highly nonlinear asymmetric wave effect could be another cause of a ship capsizing in a roll.