

CFD Modeling of Wave Loads on Offshore Wave Energy Devices

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ABSTRACT

Numerical method based on a two fluid free surface capturing technique and Cartesian cut cell mesh is being developed for the simulation of wave loads on two generic classes of offshore wave energy devices under extreme wave conditions. To validate the code, a number of test cases including slamming and forced oscillation of axisymmetric bodies near the free surface, dam break and its interaction with a small 3D box, wave generation in a 3D wave tank as well as wave interaction with a fixed wave power device have been calculated. Other test cases involving wave interaction with moving wave energy devices under realistic wave conditions will also be presented in the conference.

KEY WORDS: Free surface, water waves, wave energy devices, numerical modeling, Cartesian cut cell method.

INTRODUCTION

Green water damage to fixed and floating structures occurs as a result of high pressures and loadings imposed when wave crests inundate the structure above the waterline. In the general case of a floating object this is the result of unique combinations of the object motion and incident wave conditions. Wave slamming is also a recognised hazard and the number of reported incidents with significant structural damage due to wave impact in steep wave conditions continues to grow. These issues apply to a wide range of offshore structures including floating production storage and off-take (FPSO) vessels, floating storage and offloading (FSO) units, tension legged platforms (TLP), composed of a barge-type deck with four buoyant column legs, and wave energy devices deployed either singly or in farms fixed or moored to the seabed using tensioned cables. In many deployments, wave energy devices operate in a variety of directional sea states. The most unstable scenario is if the floating object broaches and becomes broadside to the approaching waves in beam seas. The resulting large amplitude three-degrees-of-freedom (3DOF) roll, heave and sway motions can result in breaking of mooring cables, structural damage or the possibility of capsizing. Significant research has already been initiated on different aspects of the problem. Examples include studies involving green water modelling (Hu et al, 2006; Ma et al, 2006; MacGregor et al, 2000; Buchner, 2002; and Greco et al, 2001), slamming (Zhao et al,

1993; Corte et al, 2006; Clauss et al, 2005; Easson et al, 1985; Dixon et al, 1979 and Isaacson et al 1994), fully nonlinear flow, wave diffraction (Retzler et al, 2000; and Jung, 2004), and coupled hydrodynamic and structural models (Luck and Benoit, 2004). The problem is complex and highly nonlinear so a number of approaches are being developed.

Here, we are developing a numerical wave tank (NWT) to study extreme wave loadings on two generic classes of offshore wave energy device. The first of these is a freely floating device composed of four tubular cylindrical sections of 3.5m diameter connected by hinges, having a total length of 150m. Designed to head naturally into the oncoming waves the hinged sections move relative to one another as the wave propagates along its length. Energy may be extracted via hydraulic rams at the hinges. The second device is a heaving point absorber representing a generic class of floating buoy device. It comprises a float with a hemispherical base generating oscillatory shaft motion which is converted to unidirectional rotation through a clutch which in turn drives an electricity generator. All the electro-mechanical components are housed on a structure above water. Deployment would be in a wave farm generating at least 10MW in low-medium sea states. The heave device has been studied experimentally in the laboratory, verifying a single-degree-of-freedom mathematical model of its behaviour (Stansby et al, 2005) and at intermediate ($1/10^{\text{th}}$) scale trials at NaREC in Blyth, UK. Both devices take advantage of resonance of the mechanical system, tuning their natural frequency to the wave frequency to amplify power output in low-medium seas.

The AMAZON-SC numerical wave tank (NWT) is a free surface capturing (SC) Cartesian cut cell method (Causon et al, 2001; Qian et al, 2003, 2006). The Navier Stokes equations are solved in both fluid regions and the free surface treated as a contact surface in the density field that is captured automatically during a time-marched calculation without special provision in a manner analogous to shock capturing in compressible flow (Qian et al, 2003 and 2006). A time-accurate artificial compressibility method and high resolution Godunov-type scheme replaces the pressure correction solver used in current VoF methods. MMU has extended its boundary-fitted cut-cell methodology to provide grids for problems with both static and moving boundaries in 2 and 3D (Yang et al, 1997 and Causon et al, 2001). When used with mesh adaptation (Greaves, 2004), the cut cell AMAZON-SC NWT is unrestricted in terms of boundary complexity or range of boundary movement. The handling of device motion in the above classes of device is thus straightforward and efficient without the need to generate a mesh as with classical structured or unstructured meshing methods.