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A comparison between Smoothed-Particle Hydrodynamics and RANS Volume of Fluid method in modelling slamming

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Abstract

The oil and gas industry requires complex subsea infrastructure in order to develop offshore oil and gas fields. Upon installation, these components may encounter high slamming loads, stemming from impact with the water surface. This paper utilises two different numerical methods, the mesh-free Smoothed Particle Hydrodynamics (SPH) approach and Reynolds Averaged Navier–Stokes (RANS) Volume of Fluid (VOF) method to quantify these loads on a free-falling object. The investigation is also interested in conducting a parameter study and determining the effect of varying simulation parameters on the prediction of slamming event kinematics and forces. The surface impact of a freefalling wedge was introduced as a case study and has been simulated using SPH and RANS, with the results being compared to an experimental investigation. It was found from the SPH simulations that particle resolution and the size of the SPH particle kernel are very important, whilst the diffusion term does not play an important role. The latter is due to the very transient nature of slamming events, which do not allow sufficient time for diffusion in the fluid domain. For the RANS simulations, motion of the wedge was achieved using the overset grid technique, whereby varying the discretising time step was found to have a pronounced impact on the accuracy of the captured slamming event. Through analysing the numerical data, one can observe that the RANS results correlate slightly better with the experimental data as opposed to that obtained from the SPH modelling. However, considering the robustness and quick set up of the SPH simulations, both of these two numerical approaches are considered to be promising tools for modelling more complicated slamming problems, including those potentially involving more intricate structures.

Keywords: Smoothed Particle Hydrodynamics; Reynolds Averaged Navier–Stokes; Slamming load; Wedge.

1. Introduction

The development of offshore oil and gas fields requires a large amount of subsea infrastructure to aid in the production and transport of reservoir fluids. This infrastructure is usually highly expensive and is not built with a significant level of redundancy, meaning that a failure can result in a complex and costly replacement operation. One cause of failure that has not been thoroughly investigated is the slamming load created during installation, which can weaken the structure.

Slamming events are defined by a high load that is exerted on a body over a short period of time [10]. They occur when a body impacts the water surface at relatively low-deadrise angles, resulting in a sudden expansion in the contact area between the fluid body and contact surface [12]. The very fast transient rise of pressures on the surface in slamming situations can cause local structural damage, while absorption of slam loads can cause global structural failure. Slamming loads can also excite modal vibration in the structure, imposing high cyclic loads and reducing the fatigue life of the structure. They may also permanently weaken the structure and increase its chance of failure at loads below the initial design considerations.

Many forms of investigation have been conducted to quantify the loading arising from slamming events. This includes full-scale experiments, laboratory model experiments of rigid or hydroelastic structures, and analytical/numerical solutions. The mathematical models include early works from Wagner [20] using momentum theory and expand to modern day

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techniques that encompass rigid or hydroelastic structures in a meshed or mesh free fluid domain.

SPH is a mesh free method, first developed by Gingold and Monaghan [6] for astronomical problems and further utilised in free surface flows by Monaghan [16]. Since then, SPH has been progressively refined for use in hydrodynamic and hydraulic problems. Unlike traditional meshed methods, SPH is especially useful for the analysis of high velocity impacts where the fluid boundary experiences high degrees of deformation [14], making it particularly effective in analysing slamming problems. Many fast transient problems such as dam-breaks and sloshing have been modelled successfully by SPH [9]. Recent developments in SPH modelling include the use of Graphic Processing Units (GPU) and of new neighbour search algorithms, which have significantly reduced the computational time of the simulation process [1,4]. Furthermore, Oger et al. [17] modelled free falling two - dimensional (2D) wedges in SPH; obtaining good correlation with experimental results.

Due to the advancement and availability of computational power, a new solution by way of RANS to resolve complex fluid problems is becoming more feasible for industry applications. It utilises discrete methods to apply a system of partial differential equations to flow-driven applications. An example of current literature utilising this approach to model slamming includes a study by Johannessen [11] on the testing of a lifeboat design in free fall during the impact phase. Additionally, a study by Larsen [13] uses similar analytical measures to focus on water entry for circular cylinders. It was concluded from both of these studies that RANS produces good correlation between pre-existing data obtained from experimental or alternative methods [11,13].

In this paper, a benchmark wedge free falling case study has been conducted using open source SPH code, DualSPHysics, (Crespo et al. [1]; Gomez-Gesteira et al. [8]; Gomez-Gesteira et al. [7]) and commercial RANS solver, Star-CCM+ [2]. The results were reviewed to assess the feasibility and accuracy of these two numerical approaches in modelling slamming. For the SPH simulations, the impact of altering smoothing length and artificial viscosity was investigated. A particle resolution study was also completed within a range of relatively small particle sizes. For the RANS simulations, a time step sensitivity study has been conducted to investigate the impact of discretising the time step on the slamming model. The kinematics of both SPH and RANS modelled wedge impacts were then compared with experimental results from Whelan [21] to ensure their accuracy.

1.1. Benchmark experiment description

The wedge free falling experiment conducted by Whelan [21] was analysed to validate his numerical model of catamaran slamming. The physical dimensions of the model are shown in Table 1 and Fig. 1. For model scaling, the normalised drop height, H^* was defined as:

$$H^* = \sqrt{\frac{2H}{L}} \tag{1}$$

Table 1
Freefalling wedge geometry.

Properties	Value
L	0.50 (m)
D	0.07 (m)
α	25 (degrees)

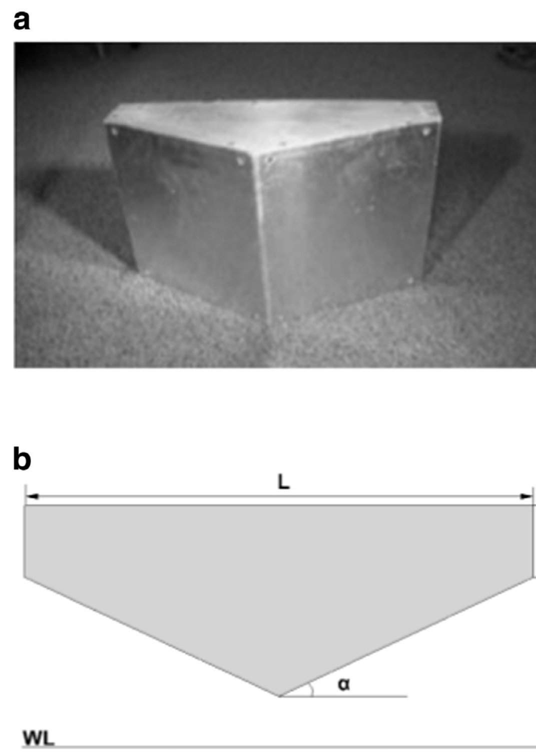

Fig. 1. Wedge geometry from Whelan [21].

where H is the drop height from the free surface to side corners and L is the beam of the model. The value of H^* was chosen to be 1.08 as it is equivalent to an effective Froude number when considering the water entry process.

2. SPH technique

2.1. SPH theory overview

SPH is a mesh-free method that utilises an array of particles to form the simulation domain. These particles represent an interpolation grid that is used to compute the fluid properties at any given point in the simulation domain by using an interpolation function called the ‘Kernel’. This is used to discretise the partial differential equations without the use of a mesh; modelling the fluid behaviour [17]. A visual representation of this system is displayed below in Fig. 2.

SPH utilises Eq. (2) to interpolate the properties of any given particle using its neighbouring particles within the influence domain [15].

$$A(\vec{r}) = \int_V A(\vec{r}')W(\vec{r}-\vec{r}', h)d\vec{r}' \tag{2}$$