

# Geometry Evaluating Piecewise Linear Interface Computation (GE-PLIC) Tailored to the Numerical Simulation of Breaking Waves

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## INTRODUCTION

The Dynamics of breaking waves are generally of significant interest for coastal engineering disciplines, since they result in considerable slamming forces on structures (Kamath et al., 2016). A key point for the accurate modelling of breaking waves is the representation of the free surface. Especially over-topping breaking waves put high demands on the capabilities of the free surface representation method, due to their complex geometries and features such as air cavities and reconnecting surfaces.

Regarding methods for free surface representation, a great variety of different approaches has been developed and implemented in CFD solvers (Düz et al., 2016). One of the methods, which has been successful over the last decades, is the Volume-of-Fluid approach (VOF) by Hirt and Nichols (1981). A key advantage of the VOF method is the strict fulfilment of mass conservation given by its approach (Pilliod and Puckett, 2004). An inherited problem of VOF are numerical smearing and diffusion of the interface, resulting from its sensitivity regarding the discretisation of fluid advection (Düz et al., 2016). Therefore, modified VOF methods are developed to ensure a sharp interface and capture the phase-distribution with sub-grid accuracy. The basic idea is, that in each cell the free surface interface is represented by a line in 2D, or a plane in 3D. The first variant of this approach was given by the Simple Line Interface Calculation method (SLIC) by Noh and Woodward (1976). Due to problems arising from SLIC's limitation to orientate the interface solely along the cartesian coordinate directions, the approach was advanced by Youngs (1982) towards the Partial Linear Interface Calculation method (PLIC), allowing for an arbitrary orientation of the interface. A crucial aspect of the PLIC method is the reconstruction of the fluid interface in each cell on the base of the volume fraction field (Düz et al., 2016). A handful of methods have been developed to approximate the plane's orientation in the cell, with most of them focusing on approximating the volume-fraction field in a 3x3 field or 3x3x3 block by a single line/plane crossing the entire field/block (Pilliod and Puckett, 2004). The most advanced algorithms aim to optimise the method's accuracy, by considering multiple possible plane orientations and selecting the one that results in the approximation with the least error in the surrounding cells (Scardovelli and Zaleski, 2003; Pilliod and Puckett, 2004; Cervone et al., 2011).

While constructing the planes in individual cells based on fitting a linear approximation to an entire 3x3x3 block works for relatively smooth geometries, the strong curvatures of the breaking waves' free surfaces demand a more detailed evaluation of the interface geometry. Error optimisation for a 3x3x3 linear approximation can lead to numerical artefacts, as they can be seen in figure 1.

Therefore, a new interface reconstruction method is developed in this project, aiming for improved numerical robustness and a more accurate representation of the complex breaking wave geometry.

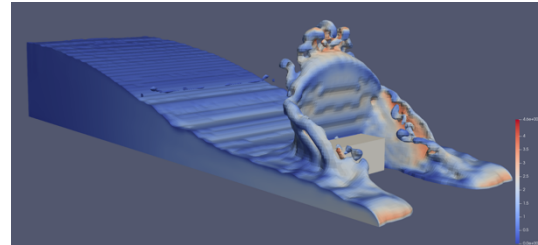


Figure 1 - CFD simulation of a dam break with obstacle, using PLIC

## METHODOLOGY

The proposed approach shall refrain from the previous method of determining a linear approximation over a length of 3 cells and rather find a local plane for each cell by predetermining its general orientation and calculating its inclination as a second step. Given by the volume fraction field, the interface must pass through cells with a volume fraction of  $0 < F < 1$  and cannot pass through cells with a volume fraction of either  $F = 1$  or  $F = 0$ . Based on this

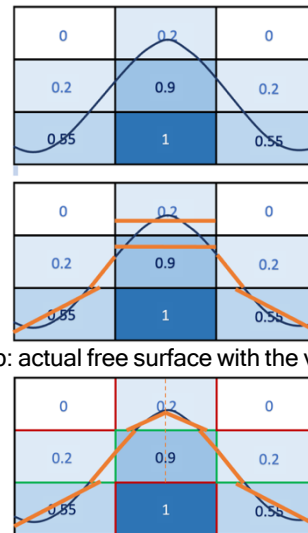


Figure 2 - top: actual free surface with the volume fractions,

middle: interface reconstruction with PLIC, bottom: interface reconstruction with GE-PLIC

definition, the cell's facets through which the interface cannot pass and the ones through which it must pass shall be predetermined by the volume fractions present in the cell's surroundings. Only after the facets through which the interface passes have been determined, shall the plane's

inclination be computed by the volume fractions across the facets. The advantage of predetermining the facets which intercept the interface lies in the possibility of identifying extreme cases and handling them accordingly. These events are of particular importance for breaking waves, since they occur in critical areas, such as the waves' tips or the area where it reconnects to the water surface. The locality of this method further allows for the theoretical construction of two planes intercepting the same facet, by orientating them symmetrical to the cells mid-axis, as given by the example in figure 2.

The pre-evaluation of the volume-fractions surrounding a cell allows for the further adaption of the PLIC method to the specific phenomena one encounters when modeling breaking waves, such as white-water, spray and submerged bubbles, as these occurrences can then be identified.

Furthermore a method for adjusting the planes localisation based on the cell's volume fraction shall be developed. While previous methods, such as presented in Gueyffier et al. (1999), are often based on geometrical considerations of the plane intercepting the cell's facets, a new approach shall be used based on a volume integral bordered by the given plane. The goal is to avoid case-predetermination, as it is necessary in Gueyffier et al. (1999), to improve the method's computational efficiency.

#### NUMERICAL MODEL

The GE-PLIC method is implemented in the Finite Differences Method based Navier-Stokes solver REEF3D::CFD, described in Bihs et al. (2016), which has already been used successfully to model breaking waves by using a Signed Distance Function for the free surface representation (Cui et al., 2022). The time advection of the interfaces is realised by an operator splitting method described by Scardovelli and Zaleski (1999). This is possible, since REEF3D::CFD uses a structured grid as a computational domain. Spatial discretisation is realised by a 5<sup>th</sup>-order WENO algorithm, while the time advection scheme of the Navier-Stokes equation is built upon a 3<sup>rd</sup>-order Runge-Kutta scheme.

#### CONCLUSION

A new method idea for the interface reconstruction in the PLIC approach has been presented. The proposed method focuses on complex free surface geometries with large local gradient changes, where an improvement over existing PLIC methods is expected. The performance of the presented method shall be tested for the case of breaking waves and further adapted for this purpose. The continued future work will include more investigations on the sensitivity and stability of the method with complex and varying scenarios.

#### ACKNOWLEDGEMENTS

The authors are grateful for the grants provided by the Research Council of Norway under the IPIRIS project (no. 308843). Some simulations were performed on resources provided by Sigma2 - the National Infrastructure for High Performance Computing and Data Storage in Norway.

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