4th CONFERENCE ON ADVANTAGES AND APPLICATIONS OF GID
The Personal Pre and Post Processor
Ibiza 2008

PFEM APPLICATIONS IN FLUID-STRUCTURE INTERACTION PROBLEMS

M.A. Celigueta, A. Larese and S. Latorre

International Center for Numerical Methods in Engineering (CIMNE)
Campus Norte UPC, Edifici C1, Gran Capitan, 08034, Barcelona
e-mail: maceli@cimne.upc.edu, antoldt@cimne.upc.edu
latorre@cimne.upc.edu
web page: http://www.cimne.com/pfem

Key words: PFEM, Fluid Dynamics, FSI

Abstract. *In the current paper the Particle Finite Element Method (PFEM), an innovative numerical method for solving a wide spectrum of problems involving the interaction of fluid and structures, is briefly presented. Many examples of the use of the PFEM with GiD support are shown. GiD framework provides a useful pre and post processor for the specific features of the method. Its advantages and shortcomings are pointed out in the present work.*

1 INTRODUCTION

Nowadays there is an increasing interest in the development of robust and efficient numerical methods for the analysis of engineering problems involving the interaction of fluids and structures accounting for large motions of the fluid free surface and the existence of fully or partially submerged bodies.

Examples of this kind are common in ship hydrodynamics, off-shore and harbor structures, ocean engineering, modeling of tsunamis, spillways in dams, free surface channel flows, liquid containers, stirring reactors, mould filling processes, etc.

The analysis of fluid-structure interaction (FSI) problems using the finite element method (FEM) with either the Eulerian formulation or the Arbitrary Lagrangian Eulerian (ALE) formulation encounters a number of serious problems. Among these we list the treatment of the convective terms and the incompressibility constraint in the fluid equations, the modeling and tracking of the free surface in the fluid, the transfer of information between the fluid and solid domains via the contact interfaces, the modeling of wave splashing, the possibility to deal with large rigid body motions of the structure within the fluid domain, the efficient updating of the finite element meshes for both the structure and the fluid, etc.

Most of these problems disappear if a Lagrangian description is used to formulate the governing equations of both the solid and the fluid domain. In the Lagrangian formulation the motion of the individual particles are followed and, consequently, nodes in a finite element mesh can be viewed as moving particles. The motion of the mesh discretizing the total domain (including both the fluid and solid parts) is also followed during the transient solution.

The Particle Finite Element Method (PFEM) is a particular class of Lagrangian formulation aiming to solve problems involving the interaction between fluids and solids in a unified manner [4].

Being developed in CIMNE during the major part of its life, PFEM's natural evolution was linked to GiD, and even to GiD's evolution.

PFEM features and some examples of its applications to civil engineering problems are presented in the following sections. GiD powerful tools for the pre and post process of the analyzed cases are shown and a list of its weak points is also made to allow a continuous improvement of its possibilities.

2 AN OVERVIEW OF PFEM

The PFEM is the natural evolution of recent work of the authors for the solution of FSI problems using Lagrangian finite element and meshless methods [6], [3], [4] and [7].

In the PFEM approach, both the fluid and the solid domains are modeled using an updated Lagrangian formulation [1]. The finite element method (FEM) is used to solve the continuum equations in both domains. Hence a mesh discretizing these domains must be generated, in order to solve the governing equations for both the fluid and solid problems in the standard FEM fashion.

The mesh nodes in the fluid domain are treated as particles which can freely move and even separate from the main fluid domain representing, for instance, the effect of water drops. A finite element mesh connects the nodes defining the discretized domain where the governing equations are solved in the standard FEM fashion.

Adaptive mesh refinement techniques can be used to improve the solution in zones where large motions of the fluid or the structure occur [7]. The Lagrangian formulation allows us to track the motion of each single fluid particle (a node). This is useful to model the separation of water particles from the main fluid domain and to follow their subsequent motion as individual particles with an initial velocity and subject to gravity forces.

PFEM involves the following steps (schematically presented in fig. 1):

1. Discretize the fluid and solid domains with a finite element mesh. In our work we use an innovative mesh generation scheme based on the extended Delaunay tessellation [3], [4] and [7].

2. Identify the external boundaries for both the fluid and solid domains. This is an essential step as some boundaries (such as the free surface in fluids) may be severely distorted during the solution process including separation and re-entering of nodes. The Alpha Shape method [2] is used for the boundary definition.

3. Solve the coupled Lagrangian equations of motion for the fluid and the solid domains. Compute the relevant state variables in both domains at each time step: velocities,

pressure and viscous stresses in the fluid and displacements, stresses and strains in the solid.

4. Move the mesh nodes to a new position in terms of the time increment size. This step is typically a consequence of the solution process of step 3.
5. Generate a new mesh if needed. The mesh regeneration process can take place after a prescribed number of time steps or when the actual mesh has suffered severe distortions due to the Lagrangian motion.
6. Go back to step 2 and repeat the solution process for the next time step.

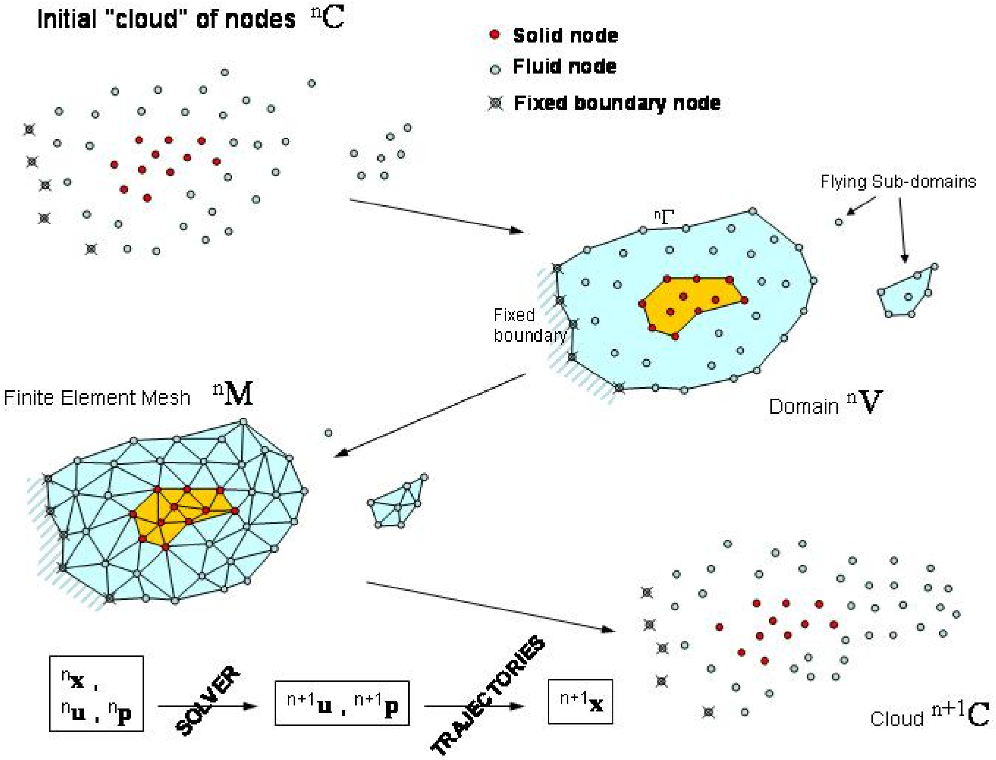


Figure 1: Sequence of steps to update a ”cloud” of nodes from time n ($t = t_n$) to time m+1 ($t = t_n + \Delta t$.

3 PFEM AND GID. ADVANTAGES AND SHORTCOMINGS

From its early beginning the development of PFEM has been strictly connected to that one of GiD. Not only has it been linked to its use, but to its evolution as well, since every new feature in GiD was rapidly introduced in the pre and post-process of PFEM and its users have always been asking for new capabilities of GiD.

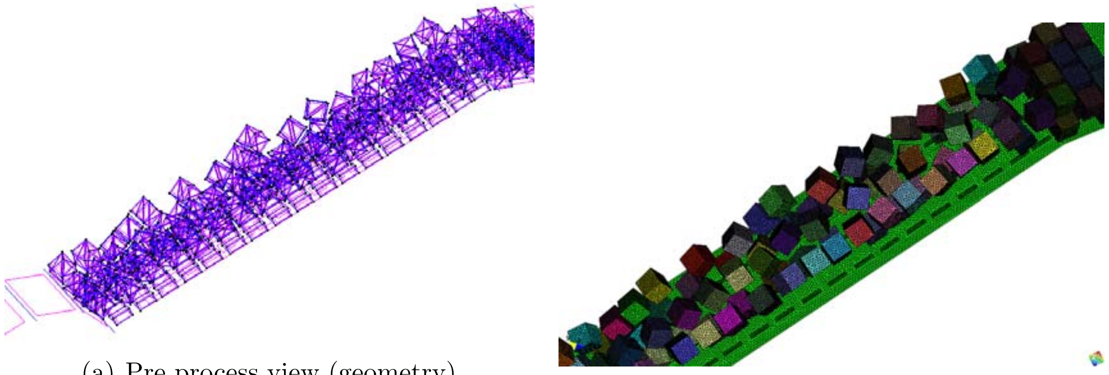
3.1 Pre-process

A simple problemtype that allows a graphical interface directly inside GiD is in continuous development in order to ease the introduction of data by the users, and it features the possibility to work with layers that separate different solid and fluid objects. The type of output results can be selected at will. At this level, no tcl-tk code has been necessary for the problemtype, only GiD language for problemtypes, which is quite understandable thanks to the very well suited tutorials.

The PFEM needs, first of all, a cloud of nodes to work with. The users get an initial geometry and mesh from GiD, using unstructured sized meshes and different layers organization, and the problemtype only takes the cloud of nodes and their properties for the PFEM, which creates a new triangulation with that information.

One of the worst drawbacks is that GiD is not a real CAD tool, but only a pre-processor for this type of work. So, sometimes the use of external powerful CAD programs becomes necessary, especially when complex geometries have to be generated.

However, the import module for external formats is quite useful and robust in these situations (fig. 2)



(a) Pre process view (geometry)

(b) Pre process view (mesh)

Figure 2: Complex geometry of multibodies imported from an external CAD tool

3.2 Post-process

The post-process is the only way to show the power of the PFEM. From the beginning, GiD has allowed PFEM users to customize the results they obtained. Since the PFEM re-meshes the domain at every time step, there are a lot of mesh files.

The feature *open several results* has made possible the creation of spectacular animations, which have been very useful when comparing numerical results with experimental tests like it is shown in fig. 3 where the sloshing phenomenon is studied [5] and the different results can be easily and directly compared. However, the dependence of this feature on the RAM space makes it very demanding in terms of hardware, taking into account that nowadays the PFEM is already able to run very large scale problems (millions of finite elements).

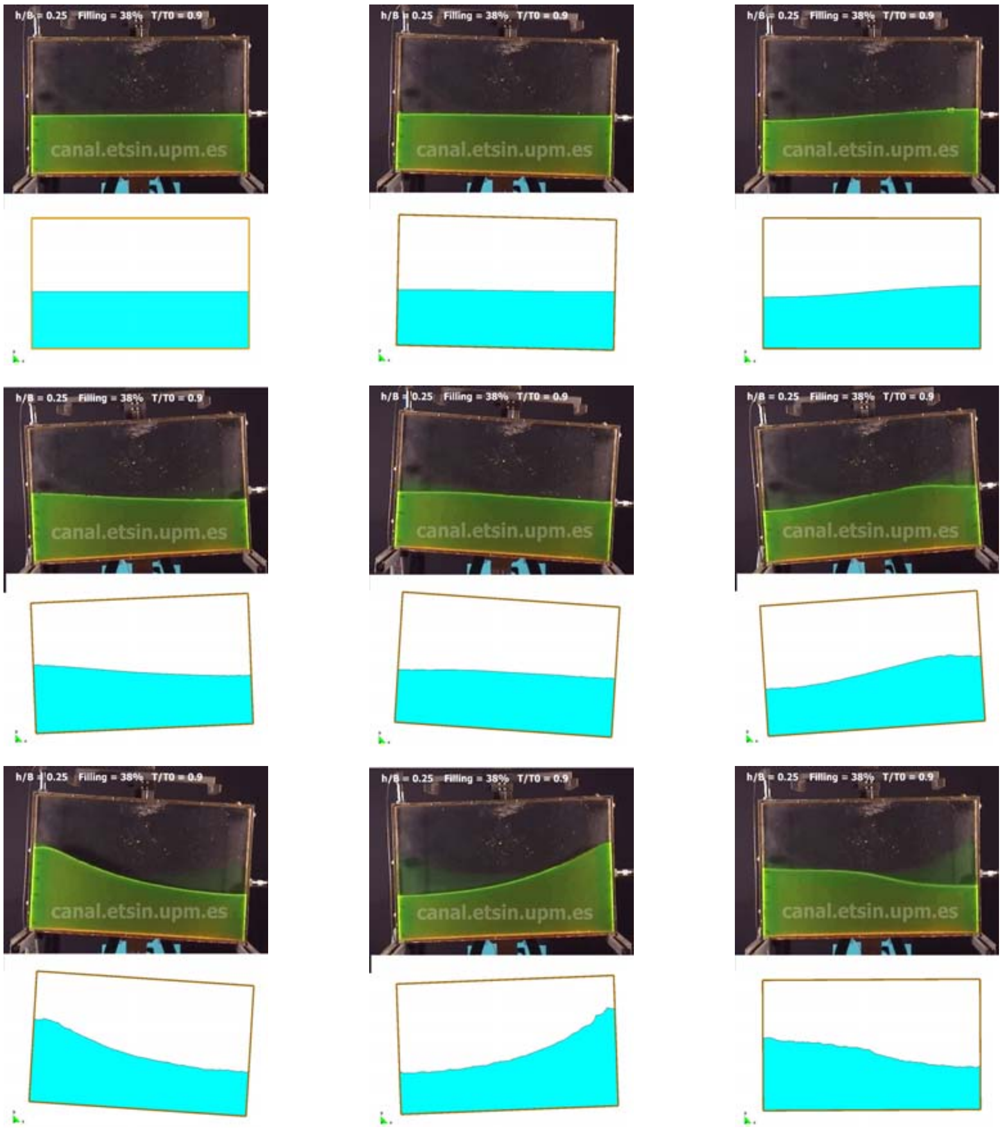


Figure 3: Comparison between PFEM and experimental results, in a sloshing analyzed phenomenon

For instance, the simulation of a multicellular box dock, pushed and carried by a heavy fluid (fig. 4), needed the creation of animations piece by piece, because each time step output files were about 200 MB (fig. 5). That was because the thickness of the problem was much smaller than the horizontal dimensions, but it could not be neglected to get a 2D model, so finally the mesh was as big as 3 million elements.

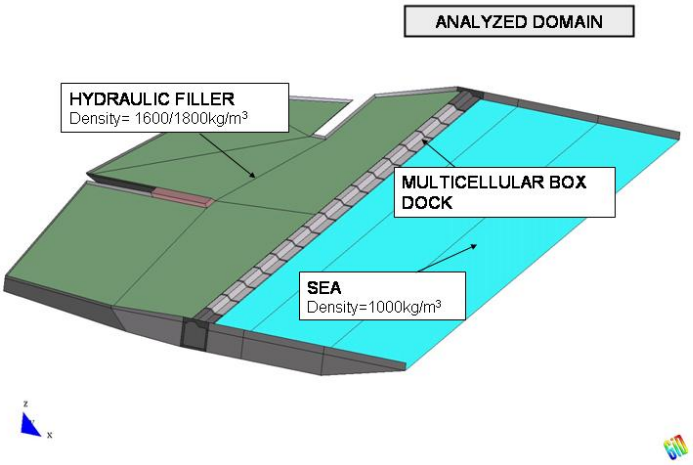


Figure 4: Domain of analysis of the 3 million elements model of a multicellular box dock between two fluids with different densities.

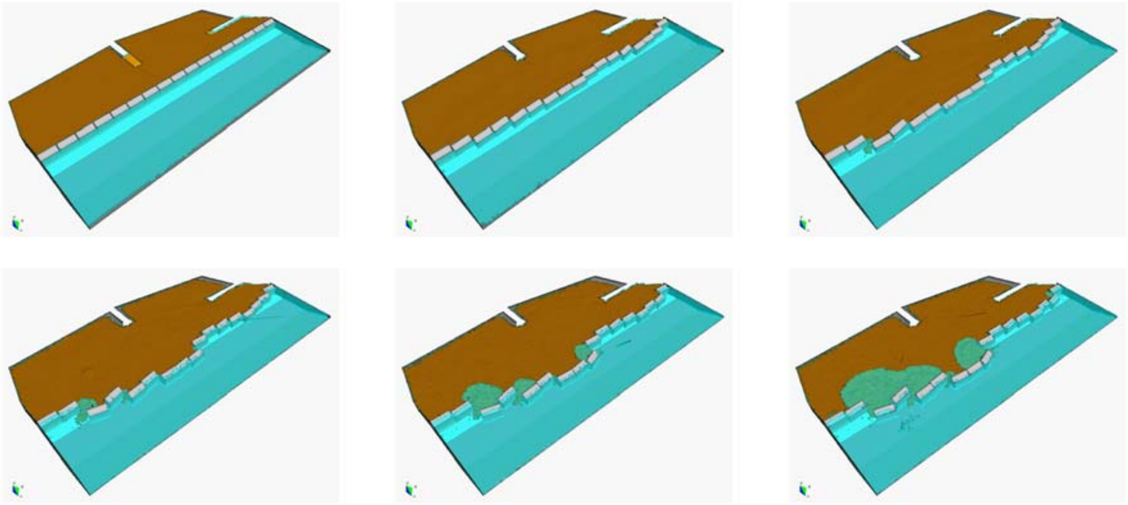


Figure 5: Evolution of the movement of the boxes because of the different density of the two fluids at the different sides

4 CONCLUSIONS

After 5 years of joint development the GiD-PFEM combination has proven to be a successful venture. The parallel evolution of both programs has been a synergic process which allowed all the parties involved to exploit their potential to a high level.

Nevertheless some issues remain which must be correctly addressed in order to fully realize the capabilities of this innovative tool suite. As already pointed out in the paper, high RAM consumption level in postprocess hampers users' productivity and limits their rate of progress.

However, all issues taken into account, the outlook for the future is extremely promising and we expect great improvements in robustness, computational cost and user-friendliness in the near term.

REFERENCES

[1] J. Donea and A. Huerta. *Finite Elements Methods for Flow Problems.* Wiley, 2003.

[2] H. Edelsbruner and Mucke. E.P. Three dimensional alpha shape. *ACM Transaction on Graphics*, (1994).

[3] S.R. Idelsohn, E. Oñate, and F. Del Pin. The particle finite element method: a powerful tool to solve incompressible flows with free-surfaces and breaking waves. *International Journal for Numerical Methods in Engineering.*, 61:61, 2004.

[4] S.R. Idelsohn, E. Oñate, F. Del Pin, and N. Calvo. Fluid-structure interaction using the particle finite element method. *Computer Methods in Applied Mechanics and Engineering*, 195:2100–2123, 2006.

[5] A. Larese, R. Rossi, E. Oñate, and S.R. Idelsohn. Validation of the particle finite element method (pfem) for simulation of free surface flows. *Accepted by: Engineering Computations*, 2008.

[6] E. Oñate, J. García, S.R. Idelsohn, and F. Del Pin. Finite calculus formulations for finite element analysis of incompressible flows. eulerian, ale and lagrangian approaches. *Computer Methods in Applied Mechanics and Engineering*, 195:3001–3037, 2006.

[7] E. Oñate, S.R. Idelsohn, F. Del Pin, and R. Aubry. The particle finite element method. an overview. *International Journal of Computational Methods*, 1:267–307, 2004.