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Element Free Galerkin Method for the Numerical Solution of the Pure Convection Problems

Ali Rahmani Firoozjaee [1], Farzad Farvizi [2], Ehsan Hendi [2]

1- Assistant professor in civil engineering department of Babol Noshirvani University of Technology
2- Ph.D. student in civil engineering department of Babol Noshirvani University of Technology

Rahmani@nit.ac.ir
He_hendi@stu.nit.ac.ir
Fa_farvizi@stu.nit.ac.ir

Abstract

In this paper, the Meshless method is introduced to the hydraulics. An element free Galerkin (EFG) method for simulation of two-dimensional shallow water flows is presented and its implementation is described. In this method only the nodal data which may be the same as those used in the finite element methods (FEMs) and a description of the domain boundary geometry are necessary; no element or grid connectivity is needed. In the EFG method the moving least squares (MLS) interpolations is used to construct the trial functions. The modelled domain is represented thorough the nodal points. A Galerkin method is applied to discretize the governing differential equations, resulting in a simultaneous equation system. An underlying cell structure for calculation of the integrals is used. The sensitivity analysis is proposed to determine the influence of the different parameters of the EFG method with solving moving cone problem. To verify the efficiency of the proposed method the shoaling problem is analyzed.

Keywords: meshless method, shallow water problems, sensitivity analysis, moving cone problem, shoaling

1. INTRODUCTION

While the generation of meshes has always posed challenges for computational scientists, this problem has become more acute in recent years. Meshless methods applied to computational fluid dynamics is a relatively new area of research designed to help alleviate the burden of mesh generation. The shallow water equations describe a thin layer of fluid of constant density in hydrostatic balance, bounded from below by the bottom topography and from above by a free surface. Generally a two-dimensional approximation of flow is used that assumes negligible vertical acceleration and a hydrostatic pressure distribution under which pressure increases linearly with depth. The non-linear hyperbolic nature of the shallow water equations makes finding analytic solutions of these equations difficult. In order to solve these equations, academic attempts can be classified into two major approaches, mesh based methods and meshless methods. Mesh based methods divide computational domain to discretized meshes, which have been named as grids in the Finite Difference Methods (FDM), cells in the Finite Volume Methods (FVM) and elements in the Finite Element Methods (FEM). Consequently the use of mesh based methods has some difficulty in problems with free surface, formidable boundaries, extremely large deformation, crack propagation, etc. [1]. Conventional mesh based methods are incapable of dealing with mentioned challenges. A variety of numerical schemes have been introduced in the literature such as the standard Galerkin finite element method to solve 1D shallow water, Saint Venant, equations [2], the discontinuous Galerkin method for 1D Shallow water flows in natural rivers [3], the finite difference method [4], the finite volume method [5], and etc.

Recently a new family of numerical methods, named meshless method, has been introduced. These methods use a set of nodes to discretize the computational domain without requiring any connectivity information. Several meshless methods have been applied to hydrodynamics. The Smoothed Particle Hydrodynamics (SPH) has been used to solve shallow water dam break flows in open channels [6]. An improved SPH method has been applied for simulating free surface flows of viscous fluids [7]. Natural Element Method (NEM) was used to solve shallow water equations with free surface flow in 2011 [9]. Firoozjaee and Afshar used the Discrete Least Squares Meshless (DLSM) method to solve shallow water equations [10].

From the above description, it can be found that the meshless methods possess the attractiveness of “no mesh” which is very advantageous and suitable for simulating shallow water flows. Therefore, it becomes the objective of the present paper to extend the application of EFG method for unsteady shallow water flows. The formulation and the numerical implementation are presented and several benchmark examples are solved to demonstrate the effectiveness of the proposed numerical method.