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Implicit formulation of material point method for analysis of incompressible materials

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Abstract

Material point method (MPM) is a particle based numerical technique with application to solid mechanics problems involving large deformations. Recently, MPM has been successfully applied in many engineering applications including solid and solid-fluid interaction problems due to its capability to model complex history dependent material behaviours. However, the conventional explicit MPM approach exhibits numerical limitations in incompressible or near incompressible material behaviour problems. We study an implicit treatment of the pressure in MPM algorithm to simulate material incompressibility avoiding artificial pressure oscillations and significantly small time steps present in the explicit MPM approach. Applying Chorin's projection method to the velocity-pressure coupled equations, an elliptic equation is solved for the pressure which is then used to solve the divergence free velocity field. The results of dam break problem show no spurious pressure oscillations and large time steps compared to the traditional explicit MPM. The ability of the present implicit MPM formulation to model incompressible materials will be an additional advantage in simulating materials with complex constitutive equations which exhibit a time dependent memory.

Key words: material point method, incompressible material, implicit pressure, projection method

1. Introduction

Material point method (MPM) is a particle based numerical technique evolved from the particle in cell method in fluid dynamics. MPM was first developed with application to solid mechanics problems where the ability of Lagrangian material points to move in an Eulerian grid was used to model history dependent materials and large deformations ([1], [2]). Later, the method has proven to be useful in a wide variety of large deformation problems including solid and solid-fluid interaction problems ([3], [4], [5] and [6]).

The previous work of MPM has often employed an explicit dynamic formulation with linear elements. The choice of linear elements in MPM has led to several problems including cell crossing errors due to the sudden movement of particles from one cell to another, mesh locking and artificial pressure fluctuations particularly due to incompressible or near incompressible conditions. Generalized interpolation material point method (GIMPM) proposed by [7] overcomes the cell crossing error and has been used in different engineering problems ([8], [9]). The most common approach to treat the incompressibility in MPM is to assume artificial compressibility and then to employ strain enhancing techniques. The work by [10] exploits two techniques, nodal mixed discretisation [11] and average nodal pressure [12] for linear triangular elements in order to avoid the locking problems of MPM in incompressible fluid problems. The B-bar method [13], which is basically a generalization of the selective integration procedure, has been applied to quadrilateral elements by [6] for incompressible plastic flow problems in two phase soil.

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