Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 175 (2017) 204 – 211

Procedia Engineering

www.elsevier.com/locate/procedia

1st International Conference on the Material Point Method, MPM 2017

Analysis of crater development around damaged pipelines using the material point method

Mario Martinelli[a,*], Faraz S. Tehrani[a], Vahid Galavi[a]

[a]*Deltares, Delft, The Netherlands*

Abstract

In this study, the material point method (MPM) is used to simulate and analyze crater development around a pipeline embedded in sand. To that end, a *double-point* MPM formulation in conjunction with an elastic-perfectly plastic soil model with Mohr-Coulomb failure criterion is used to simulate the onset and evolution of crater in fully saturated sands. The onset of failure is also simulated with standard finite element method. The results show that the *double-point* MPM formulation can satisfactorily capture the essential features of the crater development.

Peer-review under responsibility of the organizing committee of the 1st International Conference on the Material Point Method

Keywords: material point method, crater, pipeline, failure, fluidisation.

1. Introduction

When a water pipeline is damaged, it is very likely that a crater is developed around the damaged area. This can impose a high risk to urban environment where a network of underground pipelines is present. Therefore, it is highly important to understand the mechanism of crater development around damaged pipelines to minimize the risk associated with this phenomenon and to provide practical recommendations to prevent catastrophic consequences of pipeline damage.

Crater development around a damaged buried pipeline is a soil-fluid interaction problem which includes large deformation of soil around the damaged area. Therefore, simulation of the entire process cannot be carried out using

* Corresponding author.
E-mail address: mario.martinelli@deltares.nl

Peer-review under responsibility of the organizing committee of the 1st International Conference on the Material Point Method
doi:10.1016/j.proeng.2017.01.010

small-deformation analysis methods. Hence, use of a large deformation analysis approach such as the Material Point Method (MPM) that can take into account the interaction of soil and water is rather appealing.
The original formulation of MPM was developed by Harlow (1964) [1] for fluid mechanics and then applied to solid mechanics [2] and dry granular materials [3-5]. Later, the method was extended to handle saturated soils [6] with a numerical approach which uses the velocity of both solid and liquid constituent as the primary unknowns. This formulation was applied to several small and large deformation problems and is able to capture the physical response of saturated soil under dynamic loading. However, only one set of material points is used for both the solid and the liquid phase; therefore groundwater flow and the transition between free water and groundwater cannot be captured as well as fluid-like behaviour of the soil, which is typical in fluidisation and sedimentation problems. Recently, a formulation with two sets of material points (so called *double-point* formulation) was proposed [7-10] to overcome such limitations. Refinements to the original *double-point* formulation were first presented in [11] and then extended in [12], which is finally used in the current study.

2. Concepts of the *double-point* MPM

The motion of both water and solid material points (MP) is described by the system of momentum balance equations, using separate velocity fields $\boldsymbol{v}_S$ and $\boldsymbol{v}_L$ for solid and liquid constituents, respectively:

$$\nabla \cdot \boldsymbol{\sigma}'_S + (1-n)\nabla \cdot \boldsymbol{\sigma}_L + \bar{\rho}_S \boldsymbol{g} + \boldsymbol{f}_d = \bar{\rho}_S \frac{D^S \boldsymbol{v}_S}{Dt} \tag{1}$$

$$n(\nabla \cdot \boldsymbol{\sigma}_L) + \bar{\rho}_L \boldsymbol{g} - \boldsymbol{f}_d = \bar{\rho}_L \frac{D^L \boldsymbol{v}_L}{Dt} \tag{2}$$

where $\bar{\rho}_S$ and $\bar{\rho}_L$ represent respectively the partial densities of the solid and liquid, which is the ratio of the mass of each constituent with respect to the reference volume; n is the soil porosity; $\boldsymbol{\sigma}'_S$ is the effective stress tensor for solid; $\boldsymbol{\sigma}_L$ is the stress tensor for liquid; and $\boldsymbol{g}$ is the gravity vector. In equations (1)and(2), $\boldsymbol{f}_d$ is the drag force vector exerted by the liquid on the solid part. The drag force includes the non-linear velocity term that describes the additional drop of the hydraulic head observed at high flow velocities, which is common in soils with large porosity. The Forchheimer [13] equation is used to compute $\boldsymbol{f}_d$ as:

$$\boldsymbol{f}_d = n^2 \frac{\mu}{\kappa}(\boldsymbol{v}_L - \boldsymbol{v}_S) + \frac{F}{\sqrt{\kappa}} n^3 \rho_L \, |\boldsymbol{v}_L - \boldsymbol{v}_S| \, (\boldsymbol{v}_L - \boldsymbol{v}_S) \tag{3}$$

where μ is the dynamic viscosity of liquid and κ is the soil intrinsic permeability. The Kozeny-Carman formula [14] is used to update the soil intrinsic permeability as follows,

$$\kappa = \frac{D_p^2}{A} \frac{n^3}{(1-n)^2} \tag{4}$$

where D_p is the average grain size diameter and the coefficients F is computed as:

$$F = \frac{B}{\sqrt{A} n^{3/2}} \tag{5}$$

where B is a constant set to 1.75 [15]. A is also a constant which is equal to 150 according to Ergun [15].

This formulation can distinguish between mixtures characterized by low and high porosities (see Fig. 1). Fig. 1(a) shows a low-porosity mixture, where the grains of the solid skeleton are in close contact and the behaviour can be described by constitutive models developed for granular materials (solid-like response). Conversely, as shown in Fig. 1(b), in a high-porosity mixture the grains are not in contact and float together with the liquid phase. In this case, the effective stresses are equal to zero and the response of the mixture is described by the Navier-Stokes equation (liquid-like response).