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Adhesive contact algorithm for MPM and its application to the simulation of cone penetration in clay

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Abstract

Contact between bodies is one of the most challenging problems to solve, especially when combined with large deformations. For MPM, several methods have been developed to simulate frictional contact, i.e. shear stress is proportional to the normal stress via a friction coefficient; however, for cohesive soils under undrained conditions the interface shear stress is more likely a function of the undrained shear strength and independent of the normal stress (adhesive contact). This paper presents the extension of one of the most widely used contact algorithms in MPM for adhesive contact. This enhanced formulation is validated with a sliding block benchmark and applied to the simulation of cone penetration testing (CPT) in clay. CPT is an in situ test commonly used in geoengineering to determine the subsoil's stratigraphy and to estimate soil parameters. It is shown that the adhesion at the cone-soil interface affects significantly the measured cone resistance. Numerical results are compared with available analytical and experimental studies, showing the effectiveness of the proposed method to describe undrained penetration in clay.

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Keywords: contact algorithm; CPT; adhesive contact.

1. Introduction

Contact between a structure and soil is widely encountered in geotechnical applications such as penetration problems, impact of landslides on defense structures, and stability of retaining structures. Modelling of such contact is a persistent challenge in various numerical methods, especially when the contact involves large displacements and

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failure within the adjacent soil. With the Material Point Method (MPM) there are several possibilities to take into account the soil-structure interaction such as the use of interface elements [1], level-set based contact algorithms [2], or multi-velocity field formulations [3–5]. In this study, the contact algorithm proposed by Bardenhagen et al. [5] is considered. The advantage of this algorithm is that it automatically detects the contact surface and does not require any special interface elements. It proved to be efficient in modeling interaction between solid bodies as well as shearing in granular materials [6,7].

The original formulation considers only the Coulomb friction model, i.e. the maximum shear stress along the interface is proportional to the normal stress. For cohesive soils under undrained conditions, this mechanism is unrealistic. Indeed, the interface shear stress is more likely a function of the undrained shear strength and independent of the normal stress, thus an adhesive contact law seems more appropriate.

In this study, the original frictional algorithm is extended for adhesive contact as presented in Section 2. This enhanced formulation has been implemented in Anura3D (www.anura3D.eu), validated and applied to the simulation of the cone penetration test (CPT) in clay under undrained conditions. The effect of adhesion at the soil-cone interface on the measured tip resistance is investigated and compared with other numerical results as well as experimental evidences.

2. The adhesive contact algorithm

In MPM, the contact conditions are applied via the background grid and the contact problems can be completely described by the nodal variables. The applied approach is based on a multi-velocity field formulation and can be considered as a predictor-corrector scheme. The nodal velocities are predicted from the solutions of each body considered separately and then corrected using the nodal velocities of the combined set of bodies according to the contact law. Figure 1 shows a flow chart of the procedure. For further details the reader is referred to [5,8]. In the following, the focus lies on the derivation of the expression for the corrected nodal velocities including both friction and adhesion.

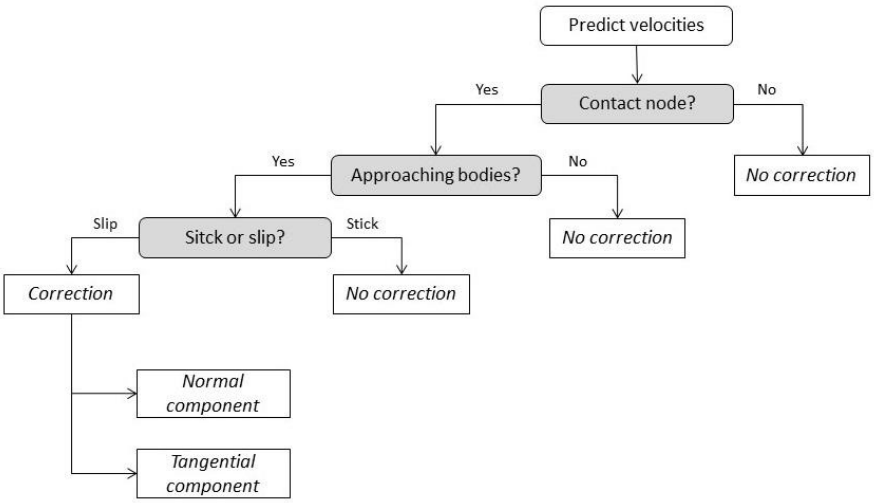

Fig. 1. Flow chart of the contact algorithm [9].

Let us consider two bodies A and B in sliding contact at time t. The single body velocities $\boldsymbol{v}_{k,A}$, $\boldsymbol{v}_{k,B}$ and the velocity of the combined system $\boldsymbol{v}_{k,S}$ are computed by solving the respective equations of motion. For a contact node k, the predicted single body velocity $\boldsymbol{v}_{k,A}$ of body A is corrected from:

$$\tilde{\boldsymbol{v}}_{k,A} = \boldsymbol{v}_{k,A} + \boldsymbol{c}_{k,norm} + \boldsymbol{c}_{k,tan} \tag{1}$$