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A constitutive model for cemented clays capturing cementation degradation

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ABSTRACT

Laboratory experiments show that the effect of cementation on clays gradually diminishes as the confining pressure increases (particularly at high confining pressures) due to the degradation of cementation bonds. The main aim of this paper is to propose a constitutive model for cemented clays, referred to as the Cemented Cam Clay model (CCC), to simulate the cementation degradation during loading. The failure envelope of the proposed model is formulated to describe the behaviour of the cemented clay at a low pressure range similar to over-consolidated soils, while it merges with the Critical State Line of reconstituted sample gradually as the confining pressure continues to increase. In order to examine the stress–strain behaviour of cemented clays, an energy dissipation equation is developed inspired by the Modified Cam Clay model. The characteristics of the proposed model, including a non-associated plastic potential function and elasto-plastic stress–strain relationship, are presented in light of the Critical State concept. Validity of the proposed constitutive model derived from the modified energy equation is evaluated against triaxial test results for cemented clays available in literature.

1. Introduction

With the growth of cities and industries, suitable sites, which can be used without some ground modification, are becoming increasingly scarce. Moreover, the cost of replacing soft soils with high quality material has dramatically increased. The design engineers have various options in dealing with problematic soils such as bypassing the poor soil, replacing it with superior soil, redesigning the structure for the poor condition or improving the soil properties by mixing soil with material such as cement, lime, gypsum and fly ash amongst other ground modification techniques. The latter option can be used for surface improvement, such as road and rail subgrade improvement, or in deep soil mixing or jet grouting technologies, which are soil improvement approaches, mixing in situ soil with strengthening agents.

A number of laboratory experiments on the effect of cementation have resulted in several constitutive models for cemented clays (Horpibulsuk et al., 2010; Kasama et al., 2000; Liu and Carter, 2002; Yasufuku et al., 1997). Kasama et al. (2000) proposed a constitutive model for cemented clays extending the critical state concept by introducing the cementation effect into the energy dissipation equation. They also modified the Critical State concept to include the increase in the strength of the clay, which results in extending the stress domain. Horpibulsuk et al. (2010) simulated the behaviour of cemented clays

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Notations

A	derivative of p'^* with respect to p'
α	non dimensional anisotropic parameter
β	cementation degradation parameter
CSL	critical state line
C	shear strength contributed by cementation when $p' = 0$
d_v	total volumetric strain increment
d_v^e	elastic volumetric strain increment
d_v^p	plastic volumetric strain increment
d_ε	total plastic deviatoric strain increment
d_ε^e	elastic deviatoric strain increment
d_ε^p	plastic deviatoric strain increments
dW_{in}	internal plastic energy per unit volume
e	void ratio of the soil
ε_1	axial strain
ε_3	radial strain
f	yield function
g	plastic potential function
κ	swelling or recompression index
λ	compression index
M	slope of failure envelope of reconstituted soil
η	stress ratio
η^*	modified stress ratio
v	Poisson's ratio
p'	mean effective stress
p'^*	modified mean effective stress
p'_d	mean effective stress inducing cementation degradation
p'^*_0	modified mean effective stress on the yield surface when $q = 0$
$p'^*_{0,i}$	initial size of the yield surface
p'_0	hardening parameter – mean effective stress on the yield surface when $q = 0$
p'_i	mean effective stress at the end of consolidation stage
$p'_{y,i}$	initial mean effective yield stress
p'_Ω	p'(tension) when $q = 0$, describing the effect of cementation
ψ^*	proposed flow rule
q	deviatoric stress
q_u	unconfined compressive strength
σ'_1	axial effective stress
σ'_3	radial effect stress

via the framework of the Structured Cam Clay (SCC) model developed by Liu and Carter (2002). Their constitutive model is an extension of SCC model for cemented clays by modifying the mean effective stress, while the effect of cementation is considered to reinforce the mean effective stress (Horpibulsuk et al., 2010). The failure envelope of the extended SCC model has been assumed to be parallel to that of untreated clay and shifted by a certain intercept, which characterises the effect of cementation similar to the model proposed by Kasama et al. (2000). Furthermore, the constitutive models by Kasama et al. (2000) and Horpibulsuk et al. (2010) assumed an associated plastic potential function while (Shen et al., 2012) explained that the volumetric strains and the transition process from compressibility to dilatancy are correctly described by a non-associated model for clayey material as also suggested by Yuanming et al. (2010). Although these existing models provide a conceptual framework for the development of an appropriate constitutive model capturing the behaviour of cemented clays, the effect of cementation degradation due to the increase in the confining pressure has not been captured in these models. As suggested by Moses et al. (2003), Panda and Rao (1998) and Lo and Wardani (1999), when the confining pressure increases, the beneficial effects of cementation may diminish as a result of cementation degradation. Therefore, the failure envelope of the cemented clay gradually merges with that of reconstituted clay-cement mixture.

The aim of this paper is to propose an enhanced model to simulate the behaviour of cemented clays under various confining pressures. The degradation of cementation bonds due to increasing confining pressure is presented by a non-linear failure envelope of cemented clay, merging to that of reconstituted soil in high confining pressure. The development of this model is mainly based on the Modified Cam Clay (MCC) model, and when there is no effect of cementation, the model returns to its original form. The paper introduces a new plastic potential function developed through modifying the energy dissipation equation. In addition, a modified stress–strain relationship for cemented clays is presented.