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Effects of wetting and ageing on 1D elasto-viscoplastic behaviour of cement-mixed clay and model simulation

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Abstract

The combined effects of wetting, the viscous property and ageing on the one-dimensional (1D) compression characteristics of kaolin were evaluated. Two series of special constant-rate-of-strain (CRS) 1D compression tests, with sustained loading at intermediate stages, were performed on kaolin with and without cement-mixing. Most of the air-dried specimens were made partially or fully saturated at intermediate stress levels. The effects of the degree of saturation, the wetting process period, the stress level at which wetting was made, the strain rate during loading and the over-consolidation history applied by compaction during the preparation of the specimens were evaluated. The effects of wetting, viscous property and ageing, observed in the experiments, were significant and complicated. A non-linear three-component elasto-viscoplastic model, that had been modified to take into account the effects of wetting, was further modified to account for the ageing effects. The effects of wetting and ageing were described by a decrease and an increase in the inviscid yield stress at a fixed irreversible strain in the plastic component. The viscous property changed from the basic type, Isotach to TESRA as the ageing effects due to cement-hydration developed. The stress–strain relations and the time histories of stress and strain, during complicated loading and wetting histories applied in the experiments, were successfully simulated by the modified model.

Keywords: Clay; Model simulation; Oedometer tests; Three-component model; Elasto-viscoplastic property; Wetting; Ageing (IGC: D5/E13)

1. Introduction

Wetting may induce the significant compression of unsaturated loose soil (e.g., Jennings and Burland, 1962; Alonso et al., 1990; Jotisankasa et al., 2007). Since Jennings and Knight (1957) proposed an experimental method to evaluate the collapse deformation during the wetting of soil, a number of models have been proposed to describe the collapse deformation of geomaterials under various loading conditions (e.g., Wheeler et al., 2003; Gallipoli et al., 2003). Although the viscous property is not taken into account in most of these models, its significant effects have been observed not only with saturated clay (e.g., Kawabe et al., 2009), but also with compacted air-dried or unsaturated clay powder (e.g., Li et al., 2004; Deng and Tatsuoka, 2004, 2007). Therefore, it is necessary to properly evaluate the effects of the viscous property on deformation during and after wetting (e.g., De Gennaro et al., 2009). Moreover, the ageing effects on the stress–strain behaviour of natural clays and young cement-mixed soil have been studied (e.g., Burland, 1990; Leroueil

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Nomenclature

α	parameter in the viscosity function
α_{T2-A}	angle showing ageing effect
α_{T2-w}	angle showing wetting effect
β	rate-sensitivity coefficient
Δt_{wet}	duration of wetting process
Δe_m	change in measured void ratio change at wetting stage
$\Delta e_{m,f}$	value of Δe_m for fully saturated specimen at wetting stage
Δe_w	total void ratio change at wetting stage
$\Delta e_{w,f}$	value of Δe_w for fully saturated specimen at wetting stage
$\dot{\varepsilon}^e$	elastic component
$\dot{\varepsilon}^{ir}$	irreversible component
ε_1^{ir}	initial irreversible strain
$\dot{\varepsilon}_r^{ir}$	parameter in the viscosity function
$\dot{\varepsilon}_v$	vertical strain rate
θ	viscous property type parameter
θ_{end}	ultimate value of θ
ρ_c	density of kaolin particles
σ_{v-n}	net stress
σ_{v0}	initial value of σ_{v-n}
σ^f	inviscid component
σ^v	viscous component
σ_{iso}^v	Isotach type viscous component of stress
σ_{TESRA}^v	TESRA type viscous component of stress
σ_{v-n}^f	inviscid component of net vertical stress
σ_{v-n}^v	viscous component of net vertical stress
$(\sigma_{v-n}^f)_y$	inviscid yield stress in terms of net vertical stress
A_i	parameters showing ageing effect on C_c
C_c	compression index
$C_c{}^e$	compression index of elastic component
C_c^{ir}	compression index of irreversible component
C_{c0}^{ir} and C_{c1}^{ir}	values of $C_c{}^{ir}$ when S_r=0.0 and 1.0
C_r	recompression index
C_{r-A}^{ir}	recompression index during ageing process
e_0	initial void ratio at the start of test
f_{sr}	function showing the effect of S_r on ageing
g_{decay}	decay function
g_v	viscosity function
h_s	loading history parameter
m	parameter in the viscosity function
$R_{\Delta em}$	ratio of Δe_m to $\Delta e_{m,f}$
S_{rA}	minimum value of S_r for a full hydration of cement
t_1	initial time
$t_{A,i}$	constant parameters showing ageing effect on C_c
t_c	curing time
t_{CrA-1} and t_{CrA-2}	constant parameters showing ageing effect on C_r^{ir}
t_{decay}	parameter in function θ
t_p	time at the start of water percolation
w_0	initial water content (in decimal)
w_{peak}	maximum water content (in decimal)

and Marques, 1996; Tatsuoka et al., 1999, 2008b; Kongsukprasert et al., 2007). The importance of a correct understanding and an accurate evaluation of ageing effects and ageing process in geotechnical engineering practices has been demonstrated by a number of full-scale case histories and related laboratory stress–strain tests on geomaterials.

Di Benedetto et al. (2002, 2005), Tatsuoka et al. (2002, 2008a) and Tatsuoka (2007) showed that a non-linear three-component elasto-viscoplastic model (Fig. 1) can properly simulate the viscous effects on the stress–strain behaviour, including creep deformation, and the strain rate effects on the stress–strain relation of a wide variety of geomaterials (i.e., soft clay, sand, gravel, sedimentary soft rock and cement-mixed soil) in triaxial and plane strain compression, torsional and direct shear and one-dimensional compression. Deng et al. (2011) studied the effects of wetting on the stress–strain behaviour of clay powder in 1D compression and modified the model (Fig. 1) to take into account the wetting effects. Extending the above, the present study was performed to evaluate the ageing effects, as well as the wetting effects, on the elasto-viscoplastic behaviour of cement-mixed kaolin powder in 1D compression and to modify the model accordingly. Firstly, the effects of ageing on the 1D compression behaviour were evaluated by wetting compacted and uncompacted cement-mixed kaolin powder from air-dried conditions toward different degrees of saturation at different vertical stress levels, and subsequently, performing monotonic loading (ML) at a constant strain rate. Secondly, the model was modified to describe not only the eventual effects of wetting and ageing on the stress–strain behaviour, but also the process of their development. In so doing, the effects of wetting and ageing were treated as negative and positive effects, respectively, on the inviscid yield stress at a fixed irreversible strain during primary loading. The ageing effects on the viscous property were also considered. The most important contribution of the present study is that, for the first time, the effects of both wetting and ageing on the elasto-viscoplastic stress–strain behaviour of soil have been experimentally evaluated and the framework for taking these

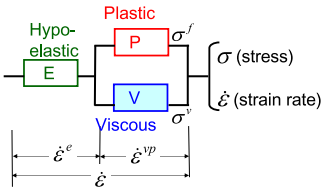

Fig. 1. Non-linear three-component model.