Soils and Foundations 2013;53(2):315–334

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Understanding sampling disturbance and behaviour of structured clays through constitutive modelling

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Received 29 August 2011; received in revised form 5 January 2013; accepted 19 January 2013
Available online 29 March 2013

Abstract

The effects of sampling disturbance on structured clays with initial states above the oedometric Intrinsic Compression Line (ICL_{oe}) are investigated numerically by applying a modified form of the Ideal Sampling Approach (ISA) and an elasto-viscoplastic constitutive model. The main features of the behaviour of structured clays during and after sampling reported in the technical literature can be replicated. Notwithstanding the inevitable damage to the microstructure of the "nominally undisturbed" specimens, the reconsolidation procedures commonly applied in laboratory practice are confirmed to be beneficial, even where they are not conceptually justified, as is the case of the SHANSEP approach. While it is possible to determine the strength and compressibility of "ideal" specimens from numerical interpretation of laboratory tests on "nominally undisturbed" specimens, the problems related to their direct use in conventional simplified design approaches for stability and settlement predictions are highlighted.

Keywords: Clay; Consolidation; Microstructure; Visco-plasticity; Yield; Sampling; Disturbance

1. Introduction

Disturbance due to tube sampling in saturated natural clays is thought to derive from a combination of damage to the microstructure (fabric and bonding) and variation in mean effective stress compared to geostatic conditions due to excess pore pressures induced by undrained cyclic changes of deviatoric stress during sampling and to drained swelling, at equal natural water content (w_o), associated with a progressive decrease of the degree of saturation, mainly after sample extrusion (Skempton and Sowa, 1963; Ladd and Lambe, 1963; Kirkpatrick and Khan, 1984; Graham and Lau, 1988; Tanaka, 2000; Watabe and Tsuchida, 2001; Hight, 2001; Santagata and Germaine, 2002; Tanaka and Tanaka, 2006).

These processes start during drilling and continue during penetration and extraction of the sampler, transport to the laboratory, storage, extrusion of the sample, specimen preparation and assembly in the testing apparatus. They may alter the behaviour of "nominally undisturbed" specimens from that of "ideal" specimens.

Previous studies on this subject addressed several aspects:

a) the influence of sampler type and of field and laboratory techniques on the degree of disturbance (La Rochelle

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Peer review under responsibility of The Japanese Geotechnical Society.

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http://dx.doi.org/10.1016/j.sandf.2013.02.011

Nomenclature

A clay activity
B inner diameter of the sampler
B_w bulk modulus of water
c_{ae} coefficient of secondary consolidation [e-log_{10}(T)]
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$C_c{}^*$ $e_{100}{}^* - e_{1000}{}^*$ (after Burland, 1990)
CF clay fraction
$e_{100}{}^*$ intrinsic void ratio at $\sigma'_v = 100$ kPa (Burland, 1990)
$e_{1000}{}^*$ intrinsic void ratio at $\sigma'_v = 1000$ kPa (Burland, 1990)
E_{oe} oedometric modulus
I_v void index (after Burland, 1990)
$(K_o)_{NC}$ earth pressure coefficient at rest for normally consolidated UPC
κ slope of the EOP isotropic swelling/recompression line in the $v - \log_{10}(p')$ plane or in the $\ln(v) - \ln(p')$ plane, for "nominally undisturbed" specimens
κ_i slope of the intrinsic isotropic swelling/recompression line in the $v - \log_{10}(p')$ plane or in the $\ln(v) - \ln(p')$ plane
l parameter related to the first mechanism of the elasto-viscoplastic constitutive model
L length of the sampler
LI liquidity index $= (w_o - w_P)/(w_L - w_P)$
m parameter related to the first mechanism of the elasto-viscoplastic constitutive model
M strength parameter
n parameter related to the second mechanism of the elasto-viscoplastic constitutive model (assumed equal to zero in this study)
p' $(\sigma'_1 + \sigma'_2 + \sigma'_3)/3 =$ mean effective stress
p'_e equivalent mean effective stress on the ICL_{oe} corresponding to the void ratio at the end of the reconsolidation phase
p'_{cio} initial mean effective stress corresponding to the intersection of the intrinsic isotropic swelling/recompression line (ICL_i) with the elastic wall passing through the point e_o, p'_o (after Rocchi et al., 2003)
p'_{cno} initial mean effective stress linked to the initial stress state and to the yield stress ratio (YSR $= \sigma'_{vy}/\sigma'_{vo}$; after Rocchi et al., 2003)
p'_o mean effective stress at the initial in situ state
p'_{r0} residual mean effective stress after tube sampling and extrusion of the sample at zero storage time and no loss of saturation
p'_{r1} residual mean effective stress after tube sampling, transportation, storage and extrusion with no loss of saturation
p'_{r2} residual mean effective stress after tube sampling, transportation, storage extrusion and partial loss of saturation
q $(\sigma'_1 - \sigma'_3) =$ deviatoric stress
q_o deviatoric stress at the initial in situ state
r parameter of the elasto-viscoplastic constitutive model which defines the position of the current state of the material with respect to the IRYL
r_e parameter which defines the dimension of the elastic domain around the initial effective stress state of the material
r_n parameter of the elasto-viscoplastic constitutive model which defines the position of the current natural yield locus with respect to the IRYL
s' $(\sigma'_1 + \sigma'_3)/2$
$SD1$ degree of sample disturbance according to Hong and Han (2007), suffix 24 h or EOP for incremental loading (24 h) and end of primary (EOP) oedometer tests, respectively
T time
T_{90} time to 90% dissipation of excess pore pressures
t $(\sigma'_1 - \sigma'_3)/2$
t_{max} $(\sigma'_1 - \sigma'_3)_{max}/2$
t_s thickness of the sampler wall
t_{sp} presumed duration of sampler penetration
u_s shear induced pore pressure
v $1 + e =$ current specific volume
v_λ specific volume at a reference mean effective stress $p' = 1$ kPa on the EOP isotropic virgin compression line, inferred from interpretation of laboratory tests on "nominally undisturbed" specimens
$v_{\lambda i}$ specific volume at a reference mean effective stress $p' = 1$ kPa on the ICL_i
ε_a axial strain
$(\varepsilon_a)_s$ imposed compression–extension axial strains in the Ideal Sampling Approach
$\varepsilon_a{}^*$ axial strain in one dimensional compression tests after reconsolidation to the geostatic effective stress
$\dot{\varepsilon}_a$ axial strain rate
φ'_{cv} constant volume (critical state) angle of shear resistance
λ slope of the EOP isotropic virgin compression line in the $v - \log_{10}(p')$ plane or in the $\ln(v) - \ln(p')$ plane, for "nominally undisturbed" specimens
λ_i slope of the ICL_i and ICL_{oe} in the $v - \log_{10}(p')$ plane or in the $\ln(v) - \ln(p')$ plane
μ_i viscosity parameter related to the first mechanism of the elasto-viscoplastic constitutive model
μ_n viscosity parameter related to the second mechanism of the elasto-viscoplastic constitutive model
θ Lode angle
σ'_{vmax} maximum vertical effective stress applied in the SHANSEP procedure
σ'_{hmax} maximum horizontal effective stress applied in the SHANSEP procedure
σ'_{vy} vertical effective yield stress in oedometer tests above which significant irrecoverable time-dependent strains occur in structured clays