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The behaviour of a gap graded sand with mixed mineralogy

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Abstract

The compression and shearing behaviour in mixtures of soils of different granulometries and/or mineralogies has been researched extensively. The focus of the research has been to identify the key factors that might lead the behaviour to change from transitional to not transitional, where transitional behaviour is characterised by non-convergent compression paths and critical state lines that might be non-unique. A review of mixtures of different soils revealed a complex pattern of behaviour, in which transitional behaviour can be caused by relatively small changes in the proportion or nature of the soil particles. It was then assumed that the mineralogy of the matrix composed by larger grains determines the mode of behaviour. If there is a strong and stiff matrix made of quartz sand particles either larger than or at least of a similar size to the other component, then non-convergent compression paths and/or not unique CLSs are likely to occur. This paper presents the results of triaxial and oedometer tests on a range of mixtures of a quartz sand and a carbonate sand, but with a larger weaker carbonate sand component. As predicted, no transitional behaviour was seen in any mixture.

Keywords: Laboratory tests; Sandy mixtures; Gap graded soils; Transitional behaviour

1. Introduction

Many reconstituted and natural intermediate graded soils have been shown to have a ‘transitional’ behaviour for which unique Normal Compression and Critical State Lines cannot be identified (e.g. Nocilla et al., 2006; Nocilla and Coop, 2008; Ponzoni et al., 2014). The first soils described as “transitional” were gap-graded (i.e. Martins et al., 2001). Numerous gap-graded soils have since been tested to evaluate the influence of particle nature, granulometry and mineralogy (e.g. Shipton and Coop, 2012) on mixtures consisting of different grain size and/or types. However, a clear picture has not yet emerged.

In the case of sand, an apparently near-unique NCL is obtained only when grain crushing becomes prevalent. Nakata et al. (2001a) showed that as the coefficient of uniformity increases, the yield in compression becomes less distinct and the nature of crushing changes from the sudden catastrophic onset of splitting to the gradual splitting of smaller particles. By varying only the granulometry, Altuhafi and Coop (2011) found that as three sands were changed from poorly graded to fractally graded, their compression behaviour evolved from a “sand” type with a unique NCL and large amounts of crushing, to non-convergent behaviour with no breakage. McDowell and Bolton (1998) and Coop et al. (2004) identified that because the compression or shearing at high stresses tends to make the grading of a sand fractal, breakage might be quantified as a function of the final fractal grading (Einav, 2007).

For binary mixtures of single mineralogy, several complex factors may influence breakage and compressibility (e.g.: co-ordination number, grain strength, size of larger

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Nomenclature

e	void ratio	γ_i	initial bulk unit weight
D_{50}	particle size for 50% passing of larger grains	γ_f	final bulk unit weight
d_{50}	particle size for 50% passing of smaller grains	γ_{di}	initial dry unit weight
G_s	specific gravity of soil grains	γ_{df}	final dry unit weight
M	gradient of critical state line in q:p' plane	γ_w	unit weight of water
q	deviatoric stress	ε_a	axial strain
p'	mean normal effective stress	ε_v	volumetric strain
p'_0	value of p' at start of shearing	σ'_{vmax}	maximum vertical stress
S_{ri}	initial degree of saturation	σ'_y	vertical yield stress
S_{rf}	final degree of saturation	σ_f	single particle crushing strength
v_i	initial specific volume	φ'_{cs}	critical state angle of shearing resistance
v_{20}	specific volume at 20 kPa vertical stress	ψ	state parameter
w_f	final water content		
w_i	initial water content		

particles, initial fabric, grain shape). Miao and Airey (2013) and Zhang and Baudet (2015) showed that because the breakage process tends to preserve features of the initial grading, the gap gradings tend to remain bi-modal even after compression to high stresses or intense shearing. Considering the difficulty of altering the initial bimodal grain distribution in a gap graded soil, it is reasonable to investigate the influence of this feature on transitional behaviour, since transitional behaviour also is characterised by difficulty erasing the initial differences in fabric of samples made at different initial void ratios (Todisco et al., 2017). Nevertheless, the occurrence of particle breakage does not necessarily indicate a transitional mode of behaviour (e.g. Shipton et al., 2006; Carrera et al., 2011; Shipton and Coop, 2012; Zhang and Baudet, 2013).

For binary mixtures of different mineralogies, the theory of breakage mechanics was extended to take into account their separate component features (Einav and Valdes, 2008). Nakata et al. (2001b) reported that the stronger mineral in a mixture, such as quartz, dominated the compression behaviour, and that the yield stress increases as the quartz content increases. Leleu and Valdes (2007) showed that in a specimen with a weak carbonate matrix, the quartz content does not substantially modify the compression behaviour unless the fraction of strong particles is considerable, while Evans and Valdes (2011) identified the existence of a transition fraction of weak particles that, when added to a stiff matrix, resulted in a change of regime in force transmission. The extent of the change was shown to be dependent on the relative stiffness of the particles.

2. Transitional behaviour in soil mixtures

Recent research on the transitional behaviour in gap graded sand and sand-silt mixtures by the authors and co-workers is summarised in Table 1 where the term "principal mineralogy" is the matrix mineralogy (i.e. "principal" means the larger percentage in weight). For all the gap graded mixtures the ratio of large to small grain diameters, R was estimated as the ratio between d_{max} and d_{min}, where the d_{max} is the mean value of the larger particle size distribution, and d_{min} is the mean value of the smaller particle size distribution. It should be noted that R is estimated as $R^* = D_{50}/d_{50}$ in the literature (e.g. Cabalar and Hasan, 2013; Zuo and Baudet, 2015), providing a rigorous definition of this value. Unfortunately, D_{50} and d_{50} were not always available for the gap graded soil data collected in Table 1. Nevertheless, for fairly uniform soils, the magnitude of R is reasonably similar to R^*.

In Table 1, there is one notable exception with regard to soil types. Well graded sand was not included in the table. For the varying natural fine contents, the behaviour of Thanet sand is sometimes characterised by its unique NCL, and at other times it is characterised by its non-convergent compression behaviour (Ventouras and Coop, 2009). However, the percentage of the minor constituent when a unique NCL occurred was only in the range of 5–10%.

In Table 1, for gap graded soils, non-convergent compression paths and/or non-unique CSLs were detected for mixtures with a matrix made of larger particles of quartz (the grey rows), regardless of whether the other component is of the same mineralogy or not. The only exception is the binary mixture of 60% quartz silt and 40% carbonate sand, which showed non-convergence with larger particles of another mineralogy (Shipton et al., 2006). However, in this case, the stresses applied were not as high as those reached in further tests carried out by Shipton and Coop (2012) on similar mixtures where unique NCLs were eventually encountered at extremely high stresses. This suggests that reaching high stresses is important when assessing the possibility of transitional behaviour. Regardless of whether low particle breakage is a prerequisite for transitional behaviour, Shipton and Coop (2012) reported quartz-carbonate mixtures with a quartz matrix demonstrated non-convergent behaviour with low overall breakage, and