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TECHNICAL NOTE

Mechanics of an Iron Ore Tailings Exhibiting Transitional Behaviour

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Abstract Laboratory critical state line (CSL) testing used in engineering practice to analyse the stability and liquefaction susceptibility of tailings explicitly assumes a unique CSL for a particular tailings. However, there is evidence of non-unique CSLs in some soils, a behaviour commonly referred to as "transitional behaviour". There is currently limited consensus or understanding of its applicability, what factors contribute to its occurrence, and whether there is a fundamental divergence from critical state theory or an artefact of the strain limitations of laboratory element tests. In this research, normally consolidated samples of an iron ore tailings prepared using the moist tamping and slurry deposition methods were sheared to critical state in triaxial compression tests. The results of these tests showed that a different CSL was apparent for the two specimen preparation methods used. This further emphasises the need to re-evaluate the effects of fabric on the uniqueness of the CSL, which may be a consequence of different sample preparation methods typically used to prepare laboratory element tests.

Keywords Transitional · Slurry deposited · Moist tamped · Fabric · Critical state

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1 Introduction

The current geotechnical practice for tailings characterisation relies on triaxial testing of reconstituted samples to determine the critical state line (CSL). Prevention of tailings storage facility (TSF) failures due to static liquefaction such as those that occurred in the Merriespruit (Fourie et al. 2001) and Stava (Carrera et al. 2011) TSFs, amongst others, requires accurate determination of the critical state line. The critical state approach that evaluates a soil's contractive-dilative characteristics, fundamentally assumes a unique critical state line independent of fabric, initial void ratio and stress history (Been et al. 1991; Jefferies and Been 2016). However, research shows that fabric created during sample preparation may result in non-unique critical state behaviour, defined as "transitional behaviour" by Nocilla et al. (2006), Shipton and Coop (2015) and Kwa and Airey (2016), where the term is used to indicate the determining effect of initial void ratio on subsequent behaviour, including the location and slope of the CSL. Given the reliance currently placed on whether tailings are deemed potentially contractive (initial state being above the CSL) or dilative, any ambiguities in characterisation of the CSL of a particular tailings material is a concern; many current stability analyses are deeply reliant on assessing the state parameter of in-situ tailings. Reid et al. (2020) report on a round-robin study in which 15 laboratories from around the world participated in determining the CSL for a sandy silt gold tailings. Although there was not complete consensus on the CSL achieved, 11 laboratories provided very similar results, e.g., at a mean effective stress of 100 kPa, the difference in void ratio between these laboratories was only 0.04. The relative uniqueness of the CSL obtained, irrespective of the initial void ratios used by the various laboratories (as long as they were initially above the CSL) was encouraging. However, there remains a lingering question as to whether a similarly unique CSL applies to all tailings, particularly given the convincing evidence in the literature of transitional behaviour for some soils. This paper reports results for an iron ore tailings where the CSL was found to be dependent on method of sample preparation.

Various researchers have studied differences (sometimes only slight) between soils that produce transitional behaviour. For example, Cuccovillo and Coop (1999), Ventouras and Coop (2009) found that mineralogy, particle shape and addition of fines creates fabric that affects the position of the CSL. Furthermore, Carrera et al. (2011) showed that soils with intermediate grading between clays and clean sands have more prevalence of exhibiting transitional behaviour. However, in this paper only a single tailings material was studied, the focus being on the method of sample preparation prior to triaxial shearing.

The effect of fabric resulting from a particular sample preparation method has been found to influence mobilisation of shear stress in Kogyuk sands when prepared using wet pluviation and moist tamping method at the same density and equal confining stresses by Been and Jefferies (1985). Moreover, Vaid et al. (1999) observed a potential liquefied stress state and non-uniform samples using moist tamping method whilst dilative behaviour and sample uniformity was found in slurry deposition method for samples prepared at the same void ratio. Similarly, Sadrekarimi and Olson (2012) concluded that initial fabric developed during sample preparation has an influence on ring shear behaviour such that contractive stress paths were observed in moist tamped samples whereas dilative and strain hardening behaviour was found in air-pluviated samples.

Structure in clays prepared using different methods has been shown to affect normal consolidation lines (NCLs), and to affect the critical state behaviour by Cotecchia and Chandler (1997), Madhusudhan and Baudet (2014), Ponzoni et al. (2014). Findings of Fearon and Coop (2000), Nocilla and Coop (2008), Coop (2015) show that the microfabric of clays prepared using different methods was not erased at critical state. Based on the previous studies, variance of fabric due to sample preparation has evidently been a determining factor for transitional behaviour in some soils.

2 Materials and Methods

2.1 Characterisation and Sample Preparation

Bulk samples recovered from shallow surface near the crest of a clayey iron ore TSF were used as the test material. The test samples comprised of fine-grained material having similar proportions of silts and clays of low plasticity. The iron ore tailings have a specific gravity of 3.71 and an optimum moisture content of 17% when tested using Standard Proctor compaction. The particle size distribution (PSD) curve of the iron ore tailings used in this study is presented in Fig. 1 along with the average gradings of soils that reportedly exhibit transitional behaviour at critical state by Ferreira and Bica (2006), Nocilla and Coop (2008), Ponzoni et al. (2014), Coop 2015, Xiao et al. (2016). The geomaterials shown in Fig. 1 exhibit a range of material types, with most being predominantly silty or sandy. The tailings used for this study has 98% less than 75 μm which further increases the probability of exhibiting transitional behaviour (Chang et al. 2011), Shipton and Coop (2012, 2015), Ni et al. (2004) and Thevanayagam et al. (2002). Geotechnical characterisation of the clayey iron tailings is also provided in Table 1.

The round robin study of Reid et al. (2020) produced a CSL within the consensus bands of CSLs using moist tamping. Other techniques used included slurry deposition that resulted in dilative samples. Dilative samples are considered unreliable for determining critical state conditions (Jefferies and Been 2016). Moist tamping has thus become the standard method of preparing tailings samples for triaxial testing to determine the CSL. Preparation of moist tamped samples (MT) of the iron ore tailings was used, and involved gentle crushing and sieving through a 2.36 mm sieve in order to minimize the effect of clods on shearing behaviour (Benson and

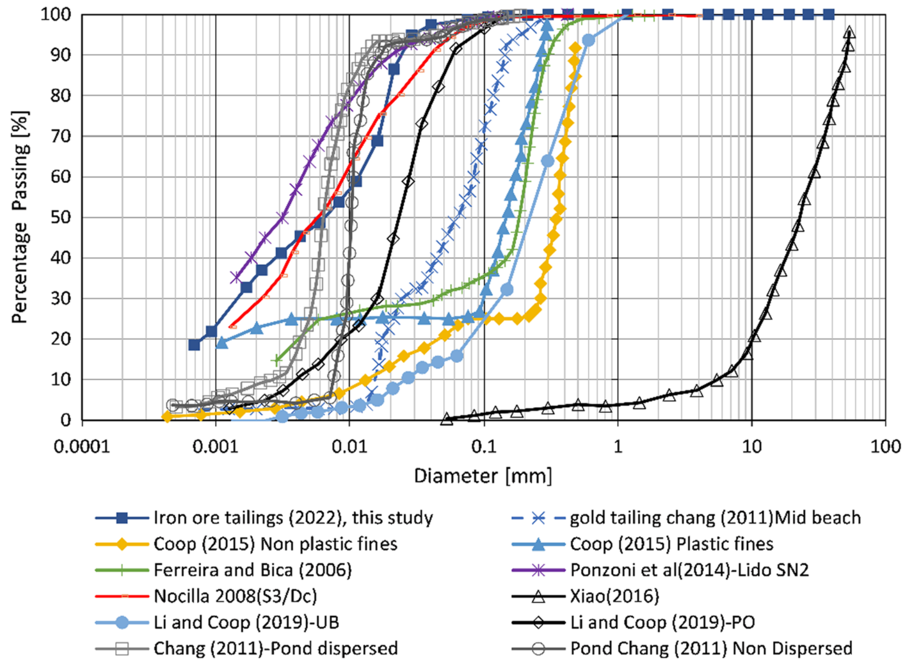


Fig. 1 Particle size distribution of soils and tailings reported to exhibit transitional behaviour

Table 1 Geotechnical properties

Geotechnical Property	Value
Specific gravity	3.71
Liquid limit	39
Plastic limit	21
Plasticity index	18

Daniel 1990; Tabet et al. 2014). The MT method followed the method used by (Ladd 1978), utilising under-compaction of samples in layers at optimum moisture content of 17%. Preparation of slurry deposited (SD) samples was similar to the method used by Sheeran and Krizek (1971) where a non-segregating slurry was prepared from disturbed bulk samples used for preparation of MT samples.

2.2 Testing Apparatus and Procedure

The laboratory tests were carried out using a GDS triaxial apparatus and two pumps were used to measure changes in cell volume and sample volume. Samples were prepared to the loosest void ratio achievable for both preparation methods while maintaining sample diameter close to 72 mm. To prevent sample collapse during preparation, a small suction, not more than 20 kPa, was applied for both MT and SD tests before introducing cell pressure. During saturation, 30 kPa effective stress was maintained and a low load cell value (less than 0.01 kPa) was used to maintain contact with the sample. Back pressure saturation was carried out until a B value ranging from 0.95 to 0.98 was achieved, followed by isotropic consolidation at varying pressures as shown in Table 2. During shearing, all triaxial compression tests were carried out to a minimum of 24% axial strain in an attempt to reach critical state conditions, and shearing was at a rate of 0.03 mm/min vertical displacement. Volumetric changes in the sample during saturation assumed a sample shape of a perfect cylinder (Head et al. 2006). The end of test moisture content was used to calculate final void ratios and volume changes during consolidation and shearing (in the drained tests). In all triaxial tests the end platens were lubricated to increase uniformity of strains during shearing e.g. Klotz and Coop (2002).

3 Experimental Results

3.1 Triaxial Test Results

Figure 2 presents the void ratio evolution during consolidation of both SD and MT tests. The details

Table 2 Summary of testing programme

Sample no	Test type	Sample type	P'_c (kPa)	e_c	P_{cs} (kPa)	q_{cs} (kPa)	e_{cs}	M_{tc}	Ψ*	Ψ**
MT1	CIU	MT	199	0.86	172	195	0.86	1.13	− 0.01	–
MT2	CIU	MT	598	0.76	468	458	0.77	0.98	0.02	–
MT3	CID	MT	101	0.91	155	164	0.85	1.06	− 0.001	–
MT4	CID	MT	299	0.81	455	439	0.76	0.98	0.001	–
SD1	CID	SD	503	0.91	790	858	0.78	1.08	–	0.15
SD2	CID	SD	403	0.92	629	689	0.80	1.09	–	0.14
SD3	CIU	SD	502	0.91	259	297	0.91	1.14	–	0.15
SD4	CIU	SD	103	1.09	62	76	1.05	1.23	–	0.14

Ψ*_state parameter based on CSL inferred from MT tests, Ψ**—state parameter based on CSL inferred from SD tests

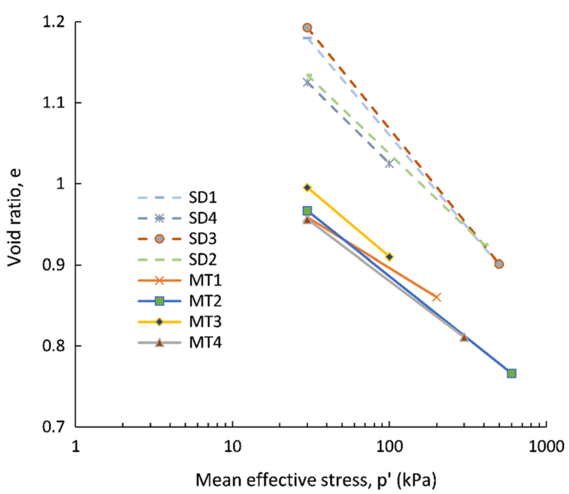


Fig. 2 Isotropic consolidation for each depositional method

of consolidation stress for each test are provided in Table 2. The ICLs of MT samples were lower than those of SD samples and ICLs of samples prepared using both preparation methods did not converge in the range of mean effective stresses used in this study (i.e., up to 600 kPa). It was observed that samples prepared at similar initial void ratios for the same method of preparation tended to converge towards a unique consolidation line. The non-convergence in isotropic consolidation curves of MT and SD samples presents a fabric effect that is dependent on method of sample preparation. The initial fabric created by different sample preparation methods was not broken down through isotropic consolidation across a range of effective stresses used in this study, resulting in non-convergence of ICLs.

Poor convergence of ICLs irrespective of the method of sample preparation indicates a variation due to initial fabric and is similar to findings of Nocilla et al. (2006), Coop (2015), Shipton and Coop (2015). Despite most authors including Coop (2015)and Shipton and Coop (2015) citing that initial specific volume (hereby compared as void ratio) as a potential indicator of transitional behaviour, Xu and Coop (2017) have shown transitional behaviour could exist at nearly equal specific volumes in soils prepared by different methods, thereby quantifying this behaviour by using parameter m (Ponzoni et al. 2014) for oedometer compression. In this study, the propensity of the MT technique to create lower initial void ratios than the SD method when aiming for the loosest possible density, similar to (Xu and Coop 2017) who were unable to create the same densities of compacted and slurry samples, further increases the importance of evaluating the effect of sample preparation method during compression and shearing.

The shearing behaviour of MT and SD tests is presented in Figs. 3 and 4. The critical state condition for each test was considered to have developed at high strains where there was minimal change in shear stress, pore pressure and volumetric strain with axial strain, which is consistent with typical practice (e.g., Shipton and Coop (2015)). MT samples reached maximum undrained shear stress at higher strains compared to the slurry deposited samples and the peak undrained shear stress for MT samples (MT1, MT2) was at about 25% axial strain as opposed to SD samples which attained peak undrained shear strength at axial strains as low as 15% for low effective stresses (sample SD4) and 12% strain in the higher effective stress test in sample SD3.

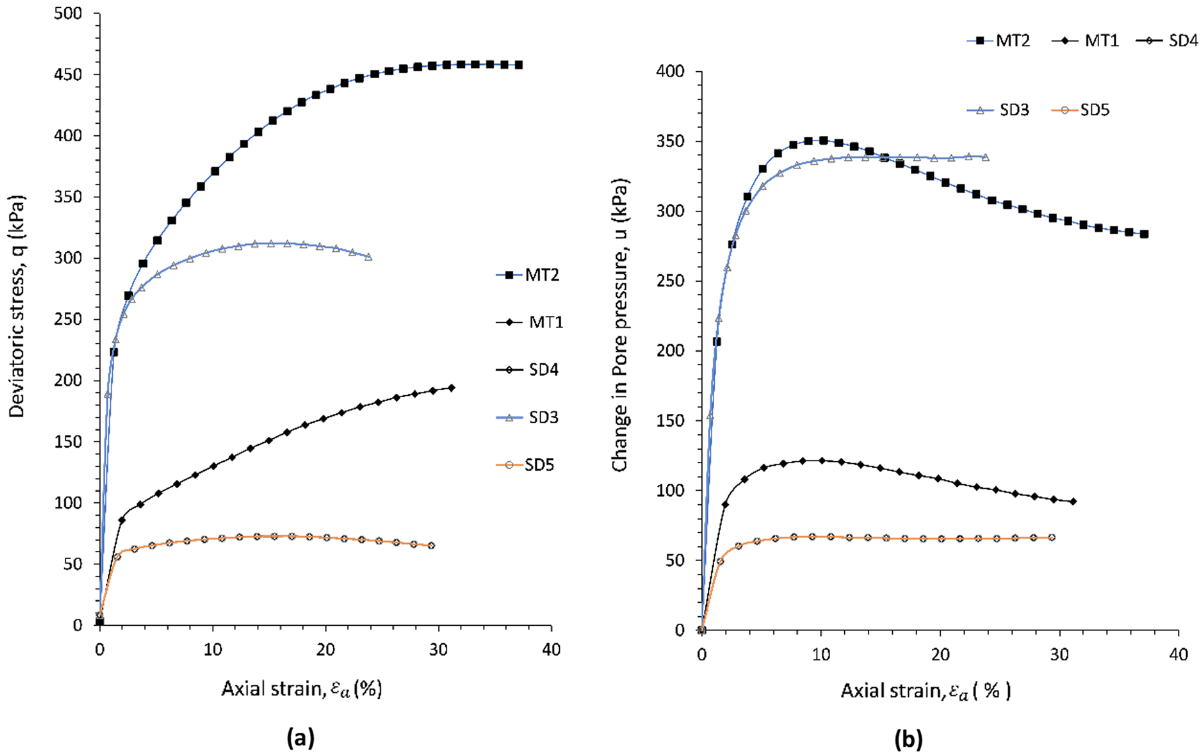


Fig. 3 Undrained triaxial compression test results: **a** Deviatoric stress results; **b** Pore pressure response

The shear stress behaviour is similar to that of Zlatovic and Ishihara (1997), Murthy et al. (2007), in that there is a variation between MT and SD tests during mobilisation of shear stress. Critical state conditions in MT and SD tests were further evaluated using pore pressure readings and/or minimal change in shear stress as presented in Fig. 3. Minimal change in pore pressure at higher strains for both preparation methods confirmed that an acceptable critical state condition was achieved based on Yoshimine and Ishihara (1998), Ishihara et al. (1975).

The drained shearing results of MT and SD are given in Fig. 4a. Similarly, drained MT tests also required higher axial strains to mobilise peak strength compared to SD tests. The difference in strain required to mobilise peak shear stress in all MT and SD tests possibly a result of differences in fabric that causes a variation in stiffness (Chang et al. 2011) and/or specimen uniformity (Thomson and Wong 2008). Fig. 4b compares the change in volumetric strain between MT and SD tests. For MT samples, the change in volumetric strain was initially contractive to 22% before transforming to slightly dilative behaviour at higher strains, whereas the volumetric change in SD samples was contractive throughout the test.

The difference in volumetric strain between MT and SD tests is related to the difference in preparation density influenced by the method of preparation.

3.2 Effect of Method of Sample Preparation

Figure 5 shows the stress path behaviour of MT and SD samples. The undrained stress path behaviour of MT tests was different to that of SD tests, such that MT tests appear to be initially contractive before changing to a quasi-steady state and phase transformation (QS-PT) behaviour (Alarcon and Leonards 1988) contrary to SD tests that exhibited only contractive behaviour. The difference in stress path behaviour between MT and SD tests was also considered to be an effect of differences in preparation density, where the MT method created denser samples compared to SD samples. It is common for silts and sands for the MT method to create looser samples than the SD method but in this research, the reverse

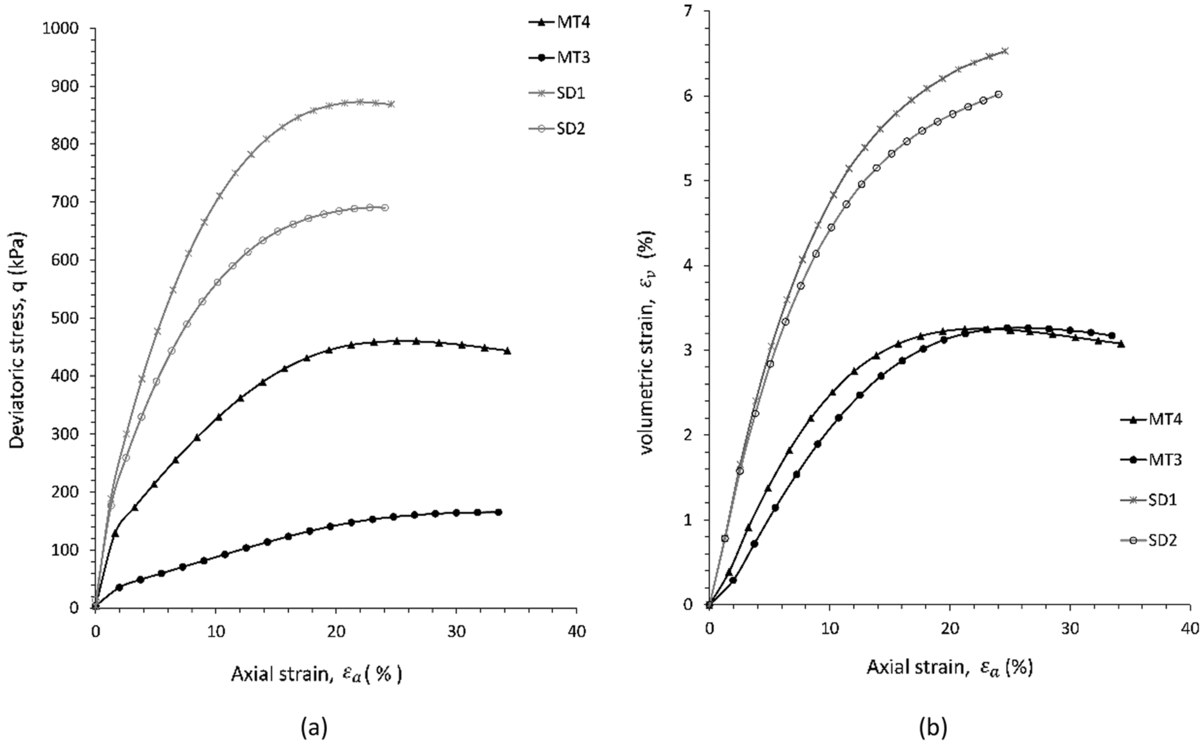
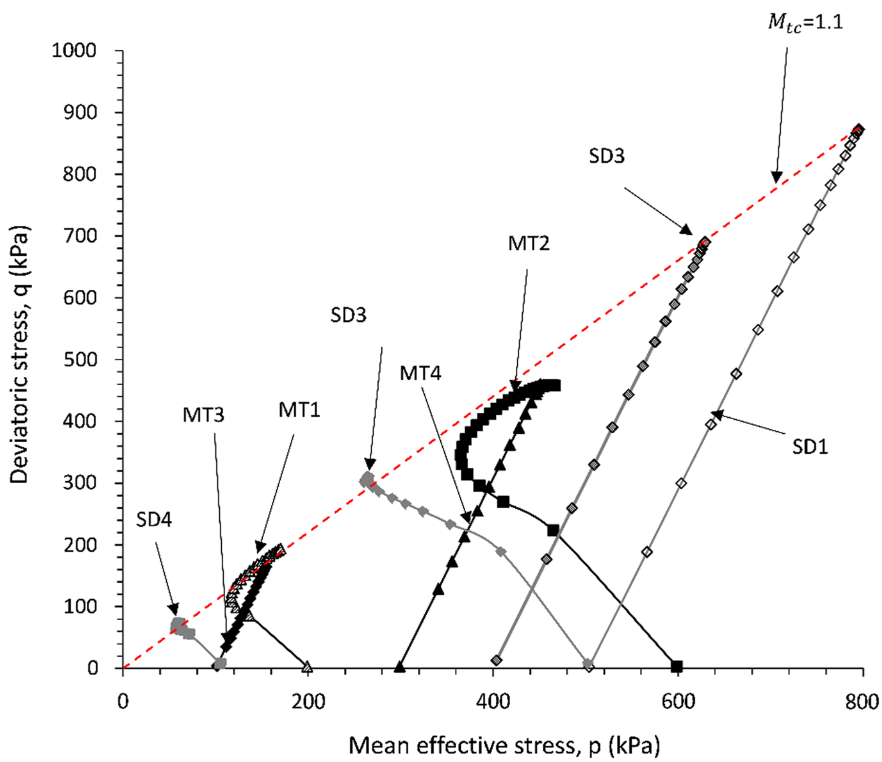


Fig. 4 Drained test results for both preparation methods: **a** drained shear stress results; **b** change in volumetric strain

Fig. 5 Stress path behaviour for SD and MT tests



was true. As a result, the stress path behaviour was inevitably influenced by preparation density, resulting in QS-PT behaviour and contractive stress paths in MT and SD tests respectively.

To further understand the effect of preparation method, the critical states of all drained and undrained results were plotted using a state diagram, as shown in Fig. 6. The critical void ratios of MT and SD tests were used to determine the slope (λ) and intercept (Γ) of the critical state line (CSL) in accordance with the power law proposed by Li and Wang (1998) as given in Eq. 1.

$$e_{cs} = A - B\left[\frac{P\prime}{P'_{ref}}\right]^{C} \quad (1)$$

where e_{cs} is the critical void ratio, A and B are material constants and C is the stress exponent (scaling parameter). P' represents the mean effective stress during shearing and P'_{ref} is the reference mean stress/atmospheric pressure which was taken as 100 kPa.

Values for λ were 0.094 and 0.106 for MT and SD tests respectively, and corresponding values of Γ were 1.35 and 1.50 respectively. Using these values, the CSL obtained using MT tests clearly differed from that obtained by SD tests.

The occurrence of two CSLs, which are dependent on the method of sample preparation is consistent with the notion of transitional behaviour induced by preparation methods that cannot be erased by shearing at mean stresses below 1000 kPa (Vaid and Sivathayalan 2000; Chu et al. 2003; Ferreira and Bica 2006; Shipton and Coop 2015).

4 Implications of Transitional Behavior on Critical State Behaviour

Transitional behaviour in soils poses a challenge of characterising potential in-situ contractive and dilative characteristics.

Figure 6 shows the region separating MT and SD CSLs, a result of what appears to be transitional behaviour in the tailings tested in this study. In Fig. 6, the region between MT and SD CSLs classifies the tailings as contractive based on the moist tamping CSL but dilative based on the SD CSL. The change in inferred behaviour of the tailings depending on the method of sample preparation clearly illustrates an important challenge of characterising some soils using Schofield and Wroth's (1968) critical state theory.

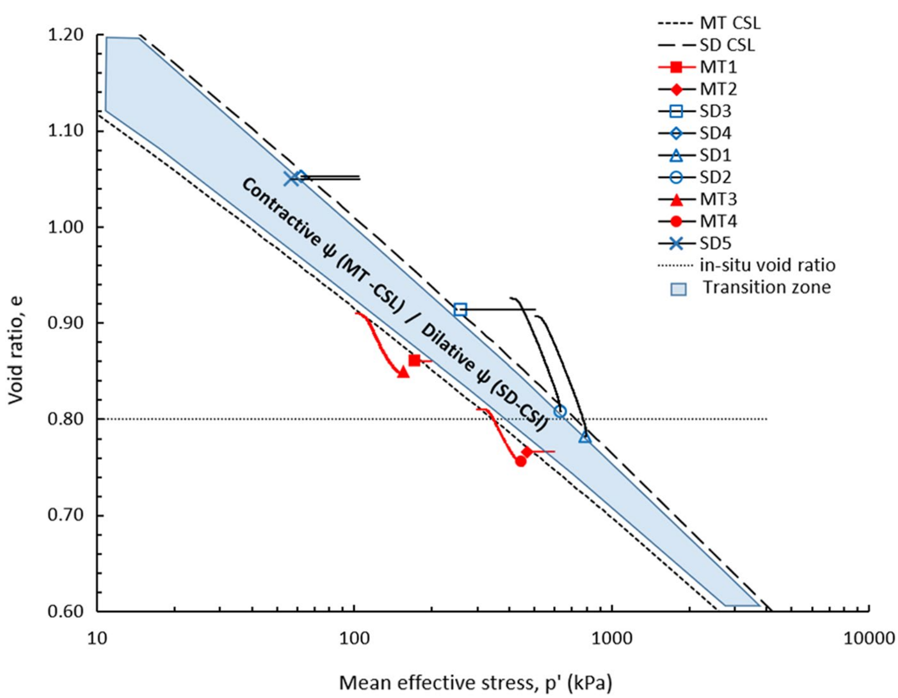


Fig. 6 Critical State diagram for MT and SD tests

Furthermore, non-unique CSLs creates uncertainty in the estimation of the maximum overburden pressure beyond which behaviour transitions from dilative to contractive. For the iron ore tailings tested here, at low mean effective stresses the tailings may be found to be dilative (from void ratio measurements compared with the CSL, for example) using both the MT and SD CSLs. At higher overburden pressure, depending on the compressibility of the tailings, the TSF's stress state may cross the CSL and end up being classified as dilative using the SD CSL, but as contractive using the MT CSL, depending on the state of the tailings. For example, in .

Figure 6, a void ratio of 0.8 would indicate transition to contractive behaviour at mean effective stresses of about 500 kPa using the MT CSL, whereas the transition to contractive behaviour occurs at around 750 kPa based on the SD CSL. Using a K_0 value of 0.6 (obtained from triaxial testing), and assuming, for illustrative purposes, the tailings are fully saturated, with hydrostatic pore pressures to the surface (such as occurs adjacent to and beneath the decant pond), these transition pressures correspond to depths of tailings of 45 m and 75 m based on the MT and SD CSLs respectively. This uncertainty is unacceptable for modern TSF practice, where the presence of contractive tailings often results in the implementation of amelioration measures such as construction of very large buttresses on the downstream slopes of TSFs deemed potentially liquefiable.

Li and Coop (2019) reported on an extensive testing campaign of iron ore tailings, taking bulk (near surface, as with the study in this paper) samples from two points on the tailings beach, near the deposition point and midway between this sample and the decant pond, while the third sample was taken at the pond. As expected, the particle size distributions of the tailings became finer with distance down the beach, i.e., the pond sample was the finest of all. They used three different sample preparation techniques, dry compaction, wet compaction and slurry deposition, and found no effect on the resulting CSLs, and they reported unique CSL's for the three different samples. They thus concluded the iron ore tailings did not exhibit transitional behaviour. A clear difference from the tailings discussed in the current work is that all three samples were coarser. Even the finest of their samples, the pond sample, had only about 3% finer than 2 µm, whereas the iron tested for this paper had some 36% finer than 2 µm.

The MT method of sample preparation is currently being widely used in the tailings industry for tests to define the CSL. The MT method is required for sandy and silty tailings (cohesionless tailings) as other preparation methods have been found to invariably produce dilative samples, which rarely reach a critical state condition due to localised slip planes forming along which deformation is concentrated. MT samples consistently produce contractive samples, which deform uniformly up to the critical state condition. The tests on iron ore tailings in this paper show contractive behaviour even for samples prepared using the slurry deposition method. Based on current approaches to determining the CSL, there is therefore no reason to believe the SD CSL is not reasonable. The question then is, why does the MT method produce such a different (and decidedly conservative) CSL. It is speculated that it may be due to the formation of agglomerates that are not completely destructured during the shearing that is possible within a triaxial cell, i.e., there is an effect of fabric that accounts for the observed differences. Current work is focussing on identifying and, if possible, quantifying this fabric effect for the iron ore tailings, with a range of techniques being trialled (such as SEM and CT tomography).

The finding by Li and Coop (2019) that the iron ore they tested showed no sign of transitional behaviour, contrasts with that of the iron ore tailings tested in this paper, which shows that the CSL has a clear dependence on method of sample preparation. Unambiguous determination of the CSL is obviously critical in order to implement a state parameter approach when analysing the stability of an existing TSF. It may be the case, based on the relatively coarser nature of the tailings tested by Li and Coop (2019), particularly the very small clay-sized fraction, that the commonly used approach of moist tamping is only suitable for material of low plasticity and which is coarser than a critical size, for example a combination of plasticity index and the percentage of clay-sized particles. This suggestion is not explored further in this paper but will be evaluated in more detail subsequently.

5 Conclusion

The effects of sample preparation method on the transitional behaviour of clayey iron tailings have been presented through triaxial testing of slurry deposited (SD) and moist tamped (MT) samples.

It was found that the effects of the sample preparation method (which likely induces a different sample structure (fabric)) resulted in non-unique critical state behaviour, i.e. what is often termed transitional behaviour. Two distinct critical state lines were found for the two different preparation methods, and the mobilisation of shear stress and the undrained stress paths were similarly found to be dependent on method of preparation, resulting in different initial densities as well In this study, the effect of sample preparation method, which likely results in a different fabric in the MT and SD samples was not erased within the axial strain limits of a conventional triaxial test.

Comparison with previously reported tests on iron ore tailings, all of which were coarser than the material tested here (a difference that was particularly apparent when considering the proportions of clay-sized particles) and all of which showed no evidence of transitional behaviour, suggests that there is the need to distinguish between tailings for which moist tamping is a suitable method of preparation, from those for which slurry deposition is more suitable. A tentative boundary is suggested to be one based on a plasticity criterion (such as plasticity index). This topic remains to be further explored.

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Data availability The data used in the analysis of the results will be provided by the authors upon request.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

References

Alarcon A, Leonards GA (1988) Discussion of liquefaction evaluation procedure by steve J. poulos, Gonzalo Castro, and John W. France June 1985 Vol 111 No 6. J Geotech Eng 114(2):232–236. https://doi.org/10.1061/(ASCE)0733-9410(1988)114:2(232)

Been K, Jefferies MG (1985) A state parameter for sands. Geotechnique 35(2):99–112. https://doi.org/10.1680/geot.1985.35.2.99

Been K, Hachey J, Jefferies MG (1991) The critical state of sands. Geotechnique 41(3):365–381. https://doi.org/10.1680/geot.1991.41.3.365

Benson CH, Daniel DE (1990) Influence of clods on hydraulic conductivity of compacted clay. J Geotech Eng 116(8):1231–1248. https://doi.org/10.1061/(ASCE)0733-9410(1990)116:8(1231)

Carrera A, Coop M, Lancellotta R (2011) Influence of grading on the mechanical behaviour of stava tailings. Geotechnique 61(11):935–946. https://doi.org/10.1680/geot.9.P.009

Chang N, Heymann G, Clayton C (2011) The effect of fabric on the behaviour of gold tailings. Geotechnique 61(3):187–197. https://doi.org/10.1680/geot.9.P.066

Chu J, Leong WK, Loke WL (2003) Discussion of "defining an appropriate steady state line for merriespruit gold tailings." Can Geotech J 40(2):484–486. https://doi.org/10.1139/T02-118/ASSET/T02-118.FP.PNG_V03

Coop M (2015) Limitations of a critical state framework applied to the behaviour of natural and transitional soils. deformation characteristics of geomaterials In: 6th international symposium, c: 115–155

Cotecchia F, Chandler RJ (1997) The influence of structure on the pre-failure behaviour of a natural clay. Geotechnique 47(3):523–544. https://doi.org/10.1680/geot.1997.47.3.523

Cuccovillo T, Coop MR (1999) On the mechanics of structured sands. Geotechnique 49(6):741–760. https://doi.org/10.1680/geot.1999.49.6.741

Fearon RE, Coop MR (2000) Reconstitution: What makes an appropriate reference material? Geotechnique 50(4):471–477. https://doi.org/10.1680/GEOT.2000.50.4.471/ASSET/IMAGES/SMALL/GEOT50-471-F1.GIF

Ferreira PMV, Bica AVD (2006) Problems in identifying the effects of structure and critical state in a soil with a transitional behaviour. Géotechnique 56(7):445–454. https://doi.org/10.1680/geot.56.7.445

Fourie AB, Blight GE, Papageorgiou G (2001) Static liquefaction as a possible explanation for the Merriespruit tailings

dam failure. Can Geotech J 38(4):707–719. https://doi.org/10.1139/cgj-38-4-707
Head KH, Kenneth H, Eng C., and Epps, R (2006) Manual of soil laboratory testing In: Soil laboratory testing, 3rd edn. Whittles, Dunbeath, Scotland
Ishihara K, Tatsuoka F, Yasuda S (1975) Undrained deformation and liquefaction of sand under cyclic stresses. Soils Found 15(1):29–44. https://doi.org/10.3208/SANDF1972.15.29
Jefferies M, Been K (2016) Soil liquefaction: a critical state approach. In: 2nd (ed) CRC Press LLC, Boca Raton
Klotz EU, Coop MR (2002) On the identification of critical state lines for sands. Geotech Test J 25(3):289–302. https://doi.org/10.1520/GTJ11090J
Kwa KA, Airey DW (2016) Critical state interpretation of effects of fines in silty sands. Geotech Lett 6(1):100–105. https://doi.org/10.1680/JGELE.15.00176/ASSET/IMAGES/SMALL/JGELE.15.00176-F5.GIF
Ladd R (1978) Preparing test specimens using undercompaction. Geotech Test J 1(1):16–23. https://doi.org/10.1520/GTJ10364J
Li W, Coop MR (2019) Mechanical behaviour of panzhihua iron tailings. Can Geotech J 56(3):420–435. https://doi.org/10.1139/CGJ-2018-0032/ASSET/IMAGES/LARGE/CGJ-2018-0032F1.JPEG
Li XS, Wang Y (1998) Linear Representation of Steady-State Line for Sand. J Geotech Geoenvironmental Eng 124(12):1215–1217. https://doi.org/10.1061/(asce)1090-0241(1998)124:12(1215)
Madhusudhan BN, Baudet BA (2014) Influence of reconstitution method on the behaviour of completely decomposed granite. Geotechnique 64(7):540–550. https://doi.org/10.1680/GEOT.13.P.159
Murthy TG, Loukidis D, Carraro JAH, Prezzi M, Salgado R (2007) Undrained monotonic response of clean and silty sands. Geotechnique 57(3):273–288. https://doi.org/10.1680/geot.2007.57.3.273
Ni Q, Tan TS, Dasari GR, Hight DW (2004) Contribution of fines to the compressive strength of mixed soils. Geotechnique 54(9):561–569. https://doi.org/10.1680/geot.2004.54.9.561
Nocilla A, Coop MR (2008) The behaviour of sub-soils from the Po river embankments: an example of transitional behaviour in natural soils. Edizioni scientifiche italiane, Naples
Nocilla A, Coop MR, Colleselli F (2006) The mechanics of an Italian silt: an example of "transitional" behaviour. Geotechnique 56(4):261–271. https://doi.org/10.1680/geot.2006.56.4.261
Ponzoni E, Nocilla A, Coop MR, Colleselli F (2014) Identification and quantification of transitional modes of behaviour in sediments of venice lagoon. Geotechnique 64(9):694–708. https://doi.org/10.1680/GEOT.13.P.166/ASSET/IMAGES/SMALL/GEOT64-0694-F1.GIF
Reid D, Fourie A, Ayala JL, Dickinson S, Ochoacornejo F, Fanni R, Garfias J, Dafonseca AV, Ghafghazi M, Ovalle C, Riemer M, Rismanchian A, Olivera R, Suazo G (2020) Results of a critical state line testing round robin programme. Geotechnique 71(7):616–630. https://doi.org/10.1680/JGEOT.19.P.373/ASSET/IMAGES/SMALL/JGEOT.19.P.373-F16.GIF
Sadrekarimi A, Olson SM (2012) Effect of sample-preparation method on critical-state behavior of sands. Geotech Test J. https://doi.org/10.1520/GTJ104317
Schofield AN, Andrew N, Wroth P (1968) Critical state soil mechanics. McGraw-Hill, London
Sheeran D, Krizek R (1971) Preparation of homogeneous soil samples by slurry consolidation. American Society for Testing and Materials, Philadelphia
Shipton B, Coop MR (2012) On the compression behaviour of reconstituted soils. Soils Found 52(4):668–681. https://doi.org/10.1016/j.sandf.2012.07.008
Shipton B, Coop MR (2015) Transitional behaviour in sands with plastic and non-plastic fines. Soils Found 55(1):1–16. https://doi.org/10.1016/j.sandf.2014.12.001
Tabet WE, Cerato AB, Miller GA (2014) Clod size and moisture condition influence on the shearing behavior of compacted soil. Geotech Geol Eng 32(5):1253–1260. https://doi.org/10.1007/s10706-014-9796-x
Thevanayagam S, Shenthan T, Mohan S, Liang J (2002) Undrained fragility of clean sands, silty sands, and sandy silts. J Geotech Geoenvironmental Eng 128(10):849–859. https://doi.org/10.1061/(asce)1090-0241(2002)128:10(849)
Thomson PR, Wong RCK (2008) Specimen nonuniformities in water-pluviated and moist-tamped sands under undrained triaxial compression and extension. Can Geotech J 45(7):939–956. https://doi.org/10.1139/T08-023/ASSET/IMAGES/LARGE/T08-023F1.JPEG
Vaid YP, Sivathayalan S (2000) Fundamental factors affecting liquefaction susceptibility of sands. Can Geotech J 37(3):592–606. https://doi.org/10.1139/t00-040
Vaid YP, Sivathayalan S, Stedman D (1999) Influence of specimen-reconstituting method on the undrained response of sand. Geotech Test J 22(3):187–195. https://doi.org/10.1520/GTJ11110J
Ventouras K, Coop MR (2009) On the behaviour of thanet sand: an example of an uncemented natural sand. Geotechnique 59(9):727–738. https://doi.org/10.1680/geot.7.00061
Xiao Y, Coop MR, Liu H, Liu H, Jiang J (2016) Transitional behaviors in well-graded coarse granular soils. J Geotech Geoenvironmental Eng 142(12):06016018. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001551
Xu L, Coop MR (2017) The mechanics of a saturated silty loess with a transitional mode. Geotechnique 67(7):581–596. https://doi.org/10.1680/jgeot.16.P.128
Yoshimine M, Ishihara K (1998) Flow potential of sand during liquefaction. Soils Found 38(3):189–198. https://doi.org/10.3208/SANDF.38.3_189
Zlatovic S, Ishihara K (1997) Normalized behavior of very loose non-plastic soils: effects of fabric. Soils Found 37(4):47–56. https://doi.org/10.3208/sandf.37.4_47