Paste 2023 – GW Wilson, NA Beier, DC Sego, AB Fourie & D Reid (eds)

doi:10.36487/ACG_repo/2355_52

Large strain shearing behaviour of untreated and polymer treated clayey silt slurry specimens

D Reid *The University of Western Australia, Australia*

B Tiwari *The University of Western Australia, Australia*

AB Fourie *The University of Western Australia, Australia*

Abstract

Polymer treatment (PT) of tailings has been observed experimentally and in physical models, resulting, in some cases, in changes to geotechnical properties including: (i) higher hydraulic conductivity, (ii) lower density at a particular vertical effective stress, (iii) a change to the critical state line (CSL), and (iv) different penetrometer response when at the same in situ state. The different CSLs observed could be theorised to converge at sufficiently high strain once the PT fabric had broken down through shearing. However, the available penetrometer test results in controlled centrifuge experiments do not support the suggestion of converging CSLs, with drastically different cone penetration test (CPT) resistance seen in PT clayey silt of importance as the CPT represents a large strain measure. To further investigate PT effects on shearing, a series of multi-stage direct simple shear and constant volume ring shear tests was carried out to investigate the large strain response of untreated (UT) and PT specimens. The tests showed consistently higher, or similar, large strain strengths from PT specimens despite their lower consolidated densities. This result is generally consistent with previous observations of an increase to CSL elevation from PT.

Keywords: *polymer treatment, large strain, element testing, critical state line*

1 Introduction

The addition of flocculants at or near to the point of discharge has become a useful technique to improve the dewatering rates of some clayey tailings in some applications. This process has been labelled variously 'secondary flocculation', 'in line flocculation and 'polymer treatment' – with the term polymer treatment (PT) adopted herein. Owing to the increased application of forms of PT, studies to characterise the effects PT may have on post-deposition geotechnical behaviour of the treated slurry have been undertaken. Broadly, these studies have indicated the following effects of PT: lower consolidated densities at a given vertical effective stress and higher permeability at a given density (Jeeravipoolvarn et al. 2009; Yao 2012; Manzotti et al. 2014; Beveridge et al. 2015; Gholami & Simms 2015; Reid & Boshoff 2015; Reid et al. 2015; Riley et al. 2015; Znidarcic et al. 2015; Reid & Fourie 2016, 2018a; Abdulnabi et al. 2022), higher undrained shear strengths at a given density (Jeeravipoolvarn et al. 2009; Yao 2012; Beier et al. 2013; Manzotti et al. 2014; Cooling & Beveridge 2015; Gholami & Simms 2015; Reid & Fourie 2016, 2017; Abdulnabi et al. 2022) and higher CSL elevation (Reid & Fourie 2016), and various contrasting outcomes when examining the effects of PT on brittleness in undrained monotonic or post-cyclic shearing (Beier et al. 2013; Gholami & Simms 2015; Reid & Fourie 2017) and drastically different penetrometer responses (Reid and Fourie 2018a), with a summary of recent studies provided by Reid and Fourie (2018b).

The effect of PT on the normal consolidation line (NCL)/critical state line (CSL) elevation and undrained strength at a given density has potentially important applications given the prevalence of methods based on the CSL to characterise the state and liquefaction susceptibility of tailings (Robertson et al. 2000, 2019; Jefferies & Been 2015; Morgenstern et al. 2016; Jefferies et al. 2019; Arroyo & Gens 2021; Reid et al. 2021). While the CSL measured in the work of Reid and Fourie (2016) adopted the conventional approach of defining the CSL using triaxial compression tests, a question that follows is whether, at shear strains higher than can be applied in the triaxial test (e.g. ~30% maximum), the effect of PT may break down in some way, leading to the treated soil eventually tending towards the UT CSL. If this were the case, it could result in major implications as to the post-peak undrained strength and brittleness of PT deposits.

To investigate the behaviour of PT slurries at a larger strain than achievable in the triaxial device, the slurry tested by Reid & Fourie (2015, 2016, 2017, 2018a) was re-created and further examined in the current study using multi-stage direct simple shear (MSDSS) tests and constant volume ring shear (CVRS) tests. These test methods enable much larger shear strains than a triaxial compression test and, therefore, a preliminary examination of whether a PT material will eventually tend towards the UT CSL.

2 Background

To provide context to the current study, a brief review of the relevant outcomes of the work of Reid & Fourie (2015, 2016, 2017, 2018a) is provided. These studies were carried out on a slurry comprising a wide gradation of sand, silt and clay-sized particles prepared through the combination of a dry mass of 31% silica fine sand (e.g. Fanni et al. 2022), 43% silica 200g and 26% kaolin; the resulting composite soil having a liquid limit of 24%, a plastic limit of 15% and a plasticity index of 9%. These index properties are consistent with many tailings. Sample preparation was carried out as follows:

1. The slurry was mixed to a gravimetric water content (GWC) of 122%.
2. Batches to be used for UT specimen preparation were then allowed to settle, with free water decanted such that the remaining slurry would be at a non-segregating GWC of 45%.
3. Batches to be used for PT specimen preparation were treated in two stages using the polymer Rheomax ETD DPW 1687 produced by BASF. A series of six 'bucket pours' between two 20 L buckets was seen to produce a visibly evident flocculant structure in the material and was therefore used for all specimens. A dosage of 500 g of polymer per dry tonne of soil was adopted, which is a dose comparable to some current applications of PT.
4. To prepare specimens for testing the slurry consolidation approach of Sheeran & Krizek (1971) was used, where the slurry was poured in 72 mm-diameter columns and vertically loaded to approximately 75 kPa, sufficient to enable free-standing specimens.
5. Triaxial tests procedures on the prepared specimens followed standard procedures including back pressure saturation, isotropic or no lateral strain (i.e. K0) consolidation, then drained or undrained shearing to measure the CSL across a wide range of stresses.
6. Monotonic and cyclic/post-cyclic direct simple shear (DSS) tests were also carried out in a parallel study, while the effect of additional shearing of the PT material (specimens referred to as PT-S) was also investigated.

Figure 1 presents the CSLs inferred through triaxial compression tests, indicating the consistently higher elevation seen for PT specimens across a wide range of mean effective stresses and shearing methods. This result could be interpreted as a form of transitional behaviour (Shipton & Coop 2015; Xu & Coop 2017; Mmbando et al. 2023). Generally consistent with the observation of a different CSL elevation, Figure 2 presents monotonic DSS tests on UT, PT and PT-S specimens, showing higher undrained strengths at a given density. Further, the process of shearing the PT specimens (e.g. PT-S tests) does not appear to have eliminated the effect of treatment in this context. The results of post-cyclic tests summarised in Figure 3, showing a similar decay of stress normalised post-cyclic undrained shear strength for UT and PT specimens, is again consistent with some intrinsic change as a result of PT, as indicated by the unique and higher elevation CSL. Finally, penetrometer results obtained through miniature cone penetration tests (CPT) in a beam centrifuge (Reid & Fourie 2018) showed far higher penetration resistances for PT specimens at equivalent densities across a wide range of penetration rates/drainage conditions. This differing response, from a penetrometer that is likely applying significantly larger shear strains than possible in a triaxial compression test, is again consistent with the different CSL elevations observed.

Clearly, given the importance of undrained shearing behaviour and post-peak brittleness on tailings storage facility (TSF) slope stability, the widespread use of the CSL to characterise tailings and the importance of the CPT to characterise TSFs, further investigation of this behaviour would be useful.

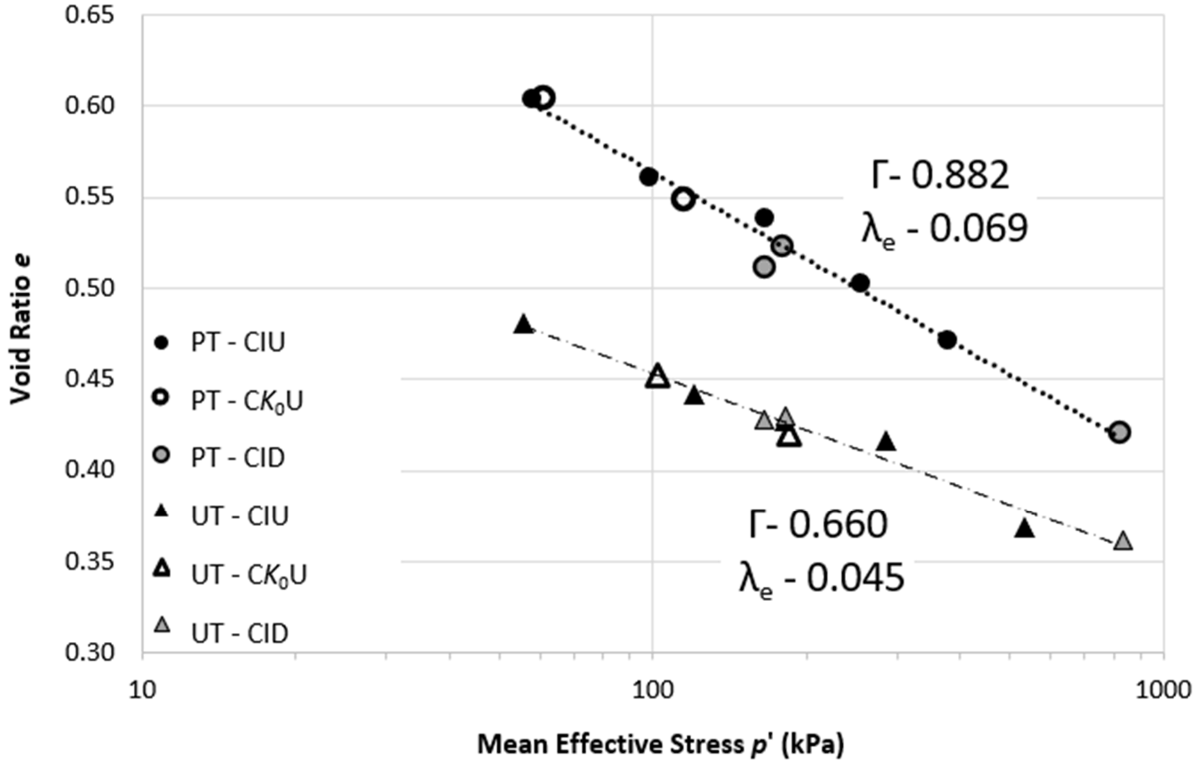

Figure 1 **Inferred CSLs of UT and PT specimens from triaxial compression tests after Reid & Fourie (2016)**

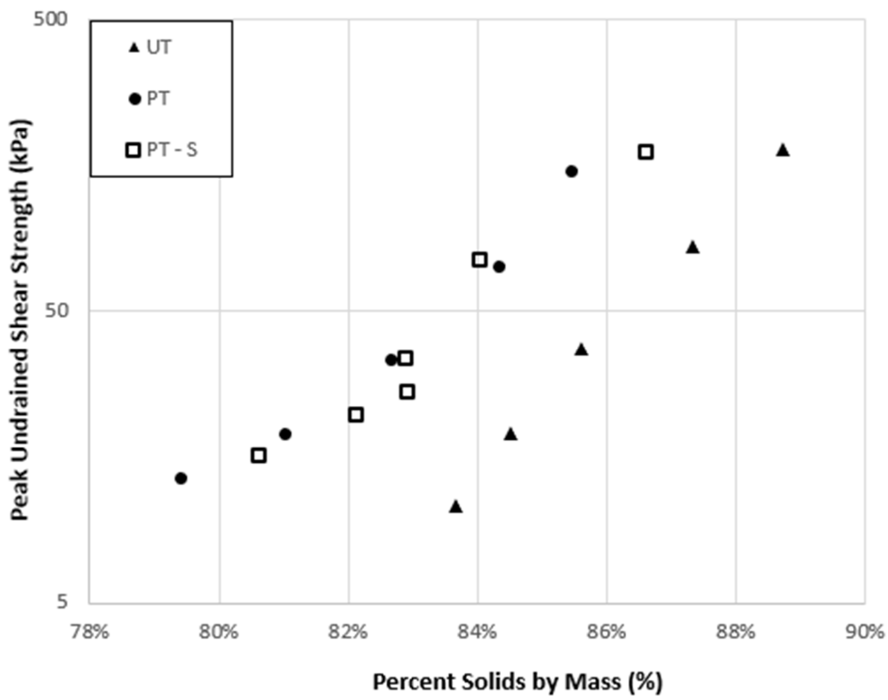

Figure 2 **Undrained strength as a function of the consolidated void ratio, UT, PT and PT-S after Reid & Fourie (2015)**

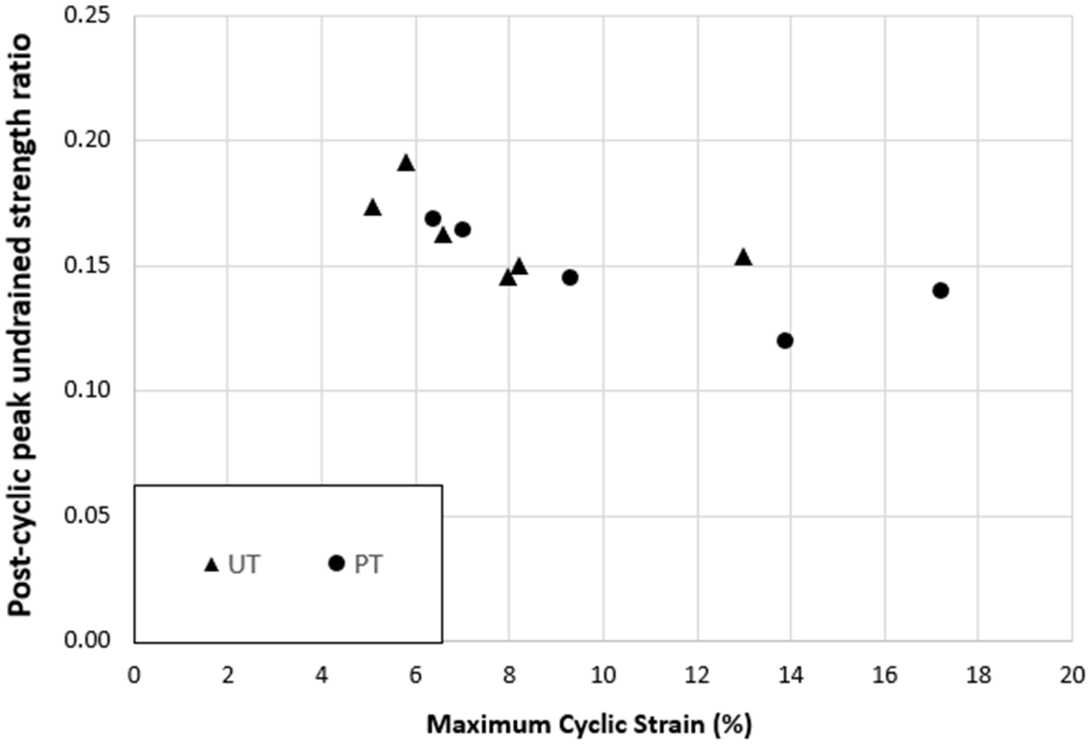

Figure 3 Post-cyclic undrained test summary presented as a peak post-cyclic strength ratio against the maximum single amplitude cyclic strain in the preceding cyclic test stage (after Reid & Fourie 2017)

3 Experimental methods

3.1 Sample preparation

Specimen preparation techniques used in the current study were consistent with those of Reid & Fourie (2014) previously outlined. As the constituents of the slurry are commercially available standard soils it was possible to closely reproduce the mixture previously use in the 2011–2014 period.

3.2 MSDSS testing

The MSDSS test utilises a conventional constant volume DSS system but, rather than simply shearing in a single direction to the maximum shear strain of the device (e.g. 20–40%, typically), the shearing direction is then reversed. The specimen is therefore sheared in multiple directions under strain-controlled loading in an attempt to remould the specimen far beyond what would occur in the single 20–30% strain available in a conventional test. While the authors are unaware of much specific discussion in the literature on the procedures and purpose of this test, it sees increasing application in the calibration of numerical models and, more generally, the investigation of clays at large strain (Zabolotnii et al. 2022; Reid et al. 2023).

MSDSS tests in the current study were carried out using an electro-mechanical cyclic direct shear system manufactured by GDS Instruments. Specimens were 70 mm in diameter, with initial heights ranging from 20–25 mm. Lateral restraint was provided by a latex membrane surrounded by a series of Teflon-coated rings. The stainless-steel porous stones included a series of protruding pins to minimise the potential for slipping of the sample at the ends.

Two methods were adopted to prepare specimens for MSDSS testing, with one of each method used for UT and PT material for a total of four tests:

1. Specimens trimmed from slurry consolidated tubes, as per previous methods discussion.
2. Specimens prepared through pouring of UT or PT slurry directly into the membrane-lined ring assembly through use of a split mould attachment that allows the maintenance of suction to hold the membrane firmly against the rings during initial pouring.

The second method was attempted as the authors were concerned that the trimming of relatively thin MSDSS specimens from slurry consolidometer tubes would lead to disturbance and densification of the specimens. The directly poured specimen preparation process, while more time consuming, avoids this potential disturbance.

The MSDSS testing involved ramping vertical effective stress to 200 kPa over a period of five hours, maintaining the load for a further two hours to ensure completion of primary consolidation, then constant volume shearing at an approximate rate of 10%/hour. A minimum of three multi-stage cycles were carried out to observe post-peak softening behaviour.

3.3 CVRS testing

The CVRS test (e.g. Stark & Contreras 1996) adopts the same principle as other constant volume methods, wherein vertical stress is adjusted actively during shearing to maintain a constant height, and thus volume, of the specimen. The advantage of the CVRS test over the MSDSS is that continuous, mono-directional shearing is possible, which is a much closer analogy to the large strain shearing that would occur in situ. The CVRS tests in the current study were carried out using a ring shear apparatus manufactured by GDS Instruments, with modifications carried out to enable constant volume testing as outlined by Mmbando et al. (2022). Specimens had an inner diameter of 70 mm and an outer diameter of 100 m, and were approximately 10 mm high.

UT specimens for CVRS testing were provided by the trimmings obtained during preparation of the slurry consolidometer-prepared MSDSS specimens. For PT specimens the treated slurry was 'spooned' directly into the CVRS cavity to as thick a depth as possible such that, after subsequent consolidation, a sufficient height for testing was achieved.

CVRS tests involved ramping vertical effective stress to approximately 190 kPa and then maintaining the load to ensure completion of primary consolidation as per the MSDSS tests. Constant volume shearing was then carried out at a rotation rate of 3 degrees/minute. Two tests using the same procedure were carried out on both PT and UT slurry.

4 Results and discussion

4.1 Consolidated densities

The results of the MSDSS and CVRS tests are first summarised based on the consolidated void ratios achieved at 200 kPa in Figure 4. This is presented to examine whether the previous observations in testing on the UT and PT specimens of this soil – that PT resulted in considerably lower consolidated densities – was reproduced herein. For context, Figure 4 includes the densities measured in beam centrifuge tests on UT and PT slurry by Reid & Fourie (2018a). The results of this comparison indicate that as per previous testing, the consolidated densities of the PT are lower than the UT specimens and generally agree with the void ratios achieved in previous testing. Further, the process of trimming specimens (versus direct pouring) for MSDSS tests has resulted in higher densities; likely the result of disturbance from trimming. Finally, although the duplicate CVRS tests show some variation (particularly for the PT specimens) in consolidated densities – likely a result of the small volume of CVRS specimens and therefore difficulty in accurate volume measurement – in general the CVRS test densities are also consistent with those seen in previous testing and the MSDSS tests.

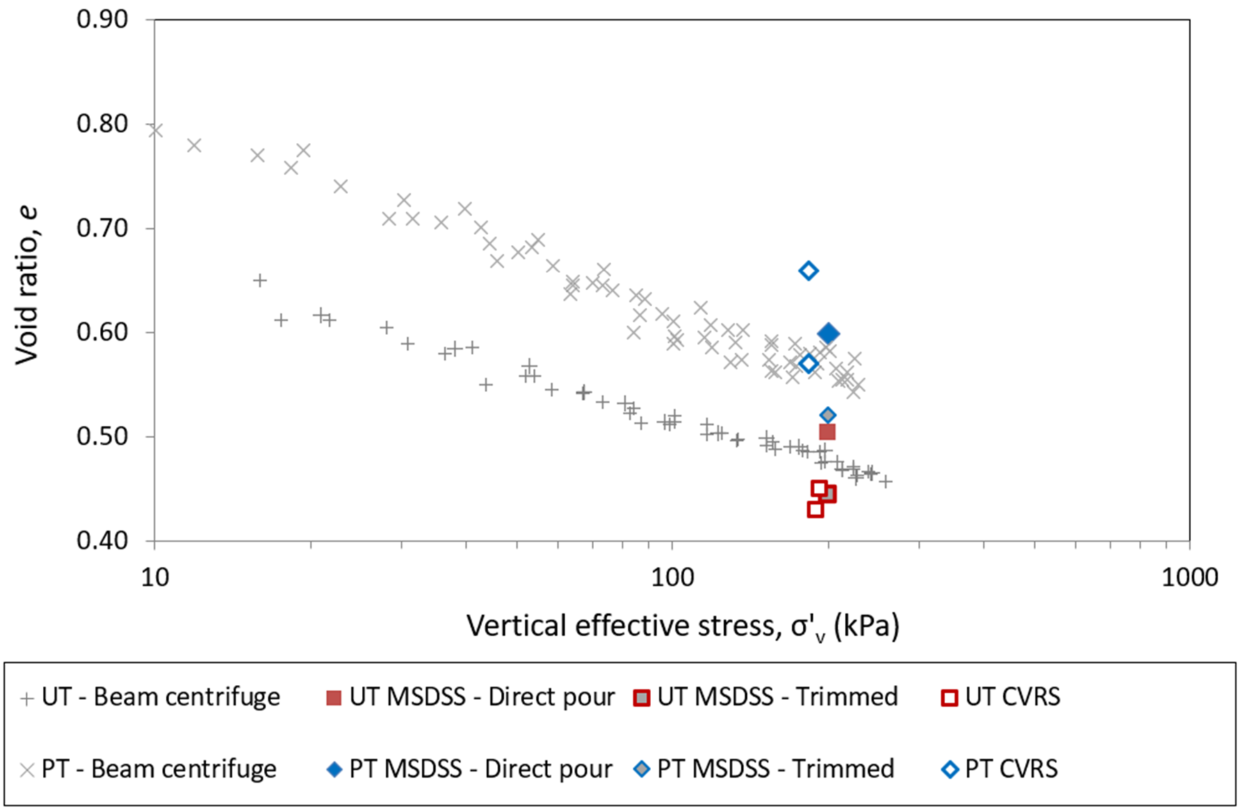

Figure 4 Comparison of consolidated densities from trimmed MSDSS, direct pour MSDSS and CVRS tests in the current study against previous consolidated densities after Reid & Fourie (2018a)

4.2 MSDSS shearing behaviour

The response of the MSDSS tests prepared through trimming slurry consolidometer specimens are compared in Figure 5, while those from direct pouring are presented in Figure 6. As it is clear that for both the UT and PT specimens the process of trimming had an effect on subsequent consolidation behaviour, separating the tests by form of preparation is therefore prudent. The test data is presented as cumulative shear strain against undrained strength ratio, with shear strain in either direction of the MSDSS process taken as a positive value and summed for the purpose of attempting to assess degradation of strength with increasing strain/remoulding of the specimens.

Two particular aspects of the MSDSS tests are apparent: (a) the PT specimens, despite being looser than the UT specimens, show less propensity for reduction in strength with strain, and (b) none of the tests are satisfactory in terms of determining a true constant large strain (residual or remoulded, depending on one's semantic preferences) undrained strength as, with the increasing loss of stiffness and reversing of shearing direction, a 'plateau' value of is not reached in any of the shearing loops. The authors have observed this behaviour in many MSDSS test programs they have carried out, and it results in significant ambiguity as to the implications or meaning of the tests. For these reasons, the CVRS is likely to provide a more rational means to investigate the remoulding process of clays through undrained shearing.

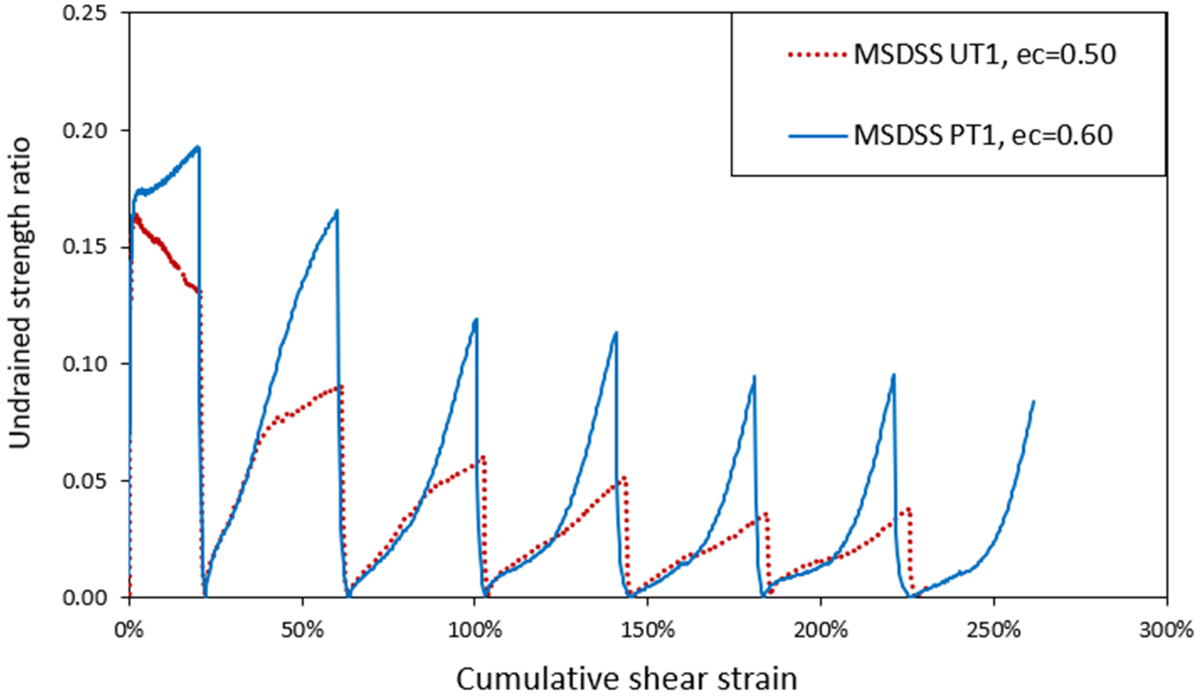

Figure 5 Comparison of MSDSS shearing behaviour of trimmed UT AND PT specimens

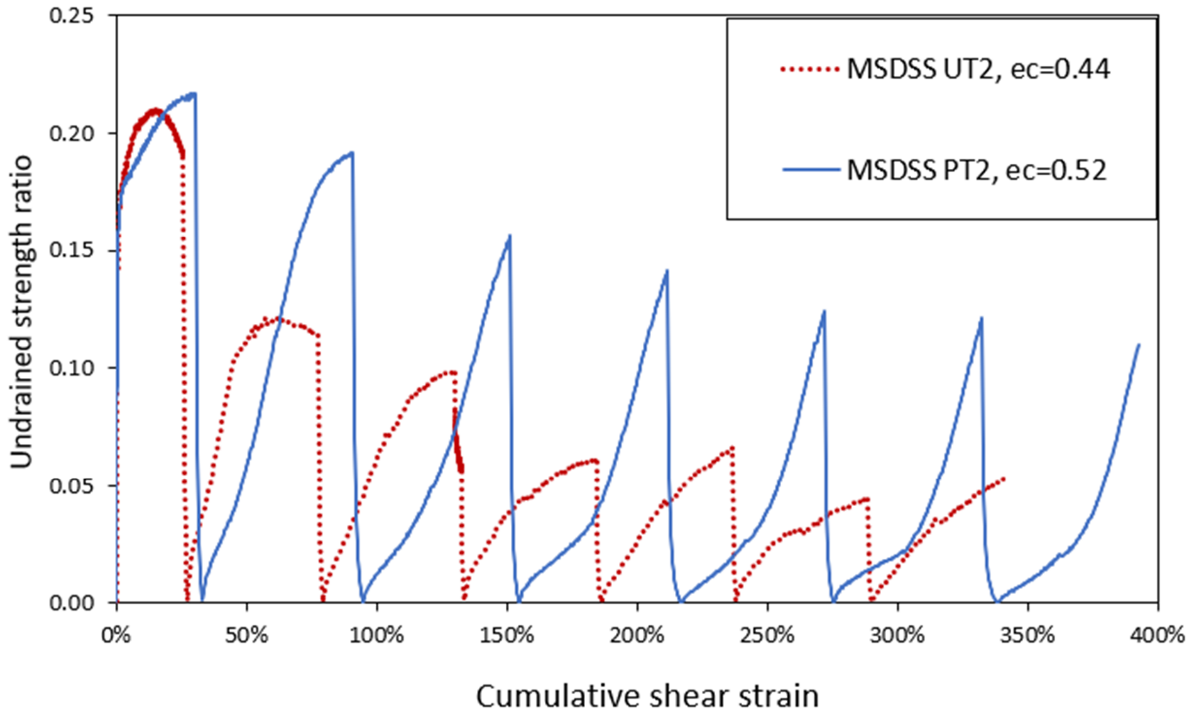

Figure 6 Comparison of MSDSS shearing behaviour of direct-poured UT AND PT specimens

4.3 CVRS shearing behaviour

The results of all four CVRS tests are summarised as rotation angle against undrained strength ratio in Figure 7. Although the CVRS, and the ring shear device more generally, is not particularly well suited to the measurement of peak strengths, the slightly higher undrained strength ratios seen from the PT specimens – along with slower post-peak decreases in strength – are generally consistent with the MSDSS tests. However, at the large strains achievable in the CVRS owing to its continuous mono-directional shearing, the two forms of specimens exhibit large strain shear strength ratios ranging from 0.06–0.07. This similar strength at large strains, despite the looser consolidated density of the PT specimens, could be taken as consistent with the higher elevation of the PT CSL. Further, it would tentatively suggest that whatever the cause of the higher CSL from PT tests, this effect is not diminished through significant shear strains achievable in the CVRS.

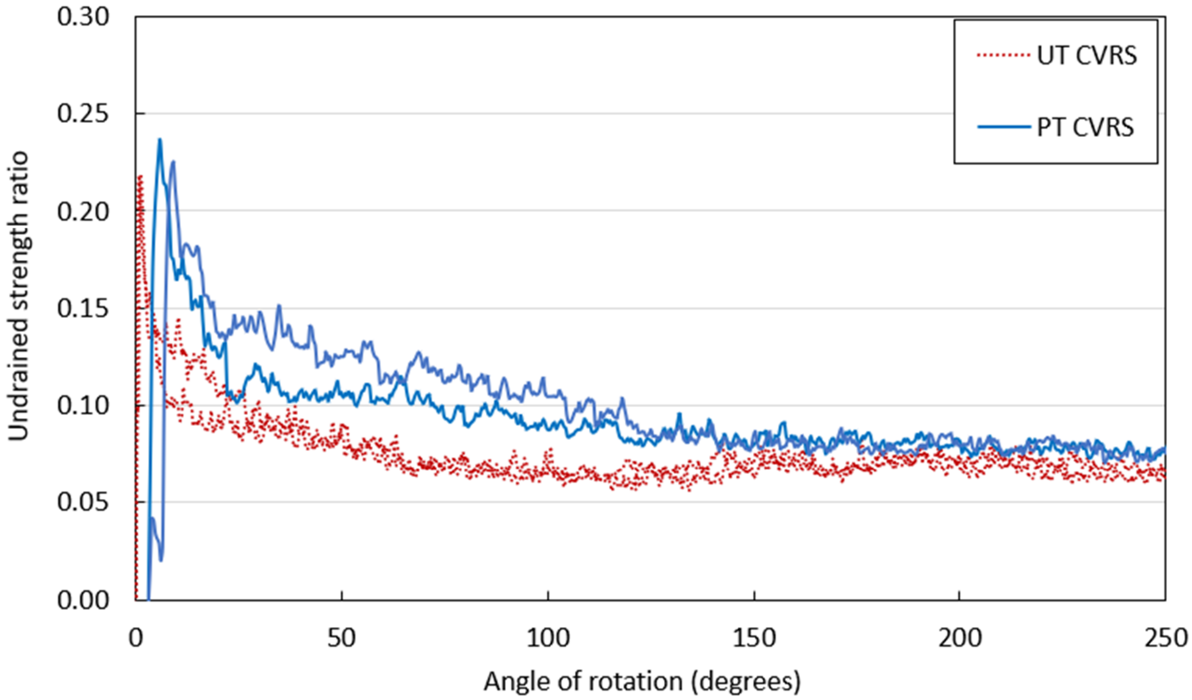

Figure 7 Comparison of CVRS behaviour of UT and PT samples

4.4 Implications

The results of the current study suggest that for the soil tested, although PT results in lower densities, there does not appear to be an increased propensity to contract and produce lower large strain strengths than in UT specimens. This outcome is generally consistent with the higher elevation CSL obtained from triaxial testing on the PT specimens and previous post-cyclic testing. However, it is inconsistent with the increased brittleness seen in situ for some PT materials (Beier et al. 2013). This may suggest that element tests on intact specimens and/or in situ tests may serve to better confirm or contradict the results of the current study. For example, no ageing had taken place on the specimens tested nor post-PT shearing, as is likely during transit along a tailings beach after deposition.

Looking beyond the potential practical applications of the work with respect to tailings strength characterisation, arguably the results of the current study could be taken as evidence of the transitional nature of the soil and the potential for PT to produce such an outcome. This is therefore useful data in the context of the hypothesised transitional behaviour of some soils as the magnitude of shear strain applied in the CVRS tests far exceeds that applied in any other study of transitional behaviour of which the authors are aware. However, cognisance of the limitations of the study is important: this study examined a single artificial gradation at a single polymer dosage. Further confirmation through testing of ‘real’ PT tailings of a variety of types, including in situ specimens that may include ageing effects, would be valuable.

5 Conclusion

This study comprised MSDSS and CVRS testing on UT and PT specimens of a well-graded soil comprising significant proportions of sand-, silt- and clay-sized particles. The test program was carried out to see if the looser consolidated densities and apparent higher elevation CSL following PT would lead to an eventual increased contractive tendency and/or reduction in shear strength at larger shear strains than those achieved in previous test programs. Specimens were prepared using the same methods as those adopted in a 2011-2014 investigation of the effects of PT on the geotechnical properties of the same soil.

The results of the study can be summarised as follows:

- Lower consolidated densities were seen to result from PT, consistent with previous studies. In the preparation of MSDSS test specimens, trimming from a slurry consolidometer tube appeared to result in densification of the samples when compared to those prepared through directly pouring the materials into the MSDSS system.
- The MSDSS tests were generally inconclusive, as a plateau remoulded strength was not achieved for any of the specimens tested. However, the qualitative behaviour seen in the PT specimens did not indicate an increased contractive tendency/remoulding process at large strain despite their lower density. Rather, the PT specimens generally exhibit higher undrained strengths than UT specimens at a given amount of cumulative (two-directional) shear strain.
- The CVRS tests were generally consistent with the MSDSS tests in that slightly higher peak strengths were observed for the PT specimens, along with somewhat slower post-peak strength loss when compared to UT specimens. However, at significant shear strains enabled by the continuous mono-directional shearing of the CVRS, the two types of specimen converged to an undrained strength ratio of approximately 0.06–0.07. This similar high strain undrained strength ratio for the two specimens, despite significantly different consolidated densities, is consistent with the observation of a higher elevation CSL of the PT specimens.

This study therefore provides some evidence that the looser densities achieved through PT may not, in some cases, make the material more susceptible to large strain contractive tendency and resulting lower remoulded strengths. However, the narrow applicability of the results – being carried out on 'fresh' specimens without ageing or shearing effects – must be acknowledged.

Acknowledgement

The authors acknowledge the assistance provided by BASF Australia Ltd in the provision of flocculant for the current study and advice on preparation methods previously provided to support earlier related studies. We also acknowledge South32 for providing UWA with the DSS system, and Alcoa, Rio Tino and BHP for providing the ring shear system as part of MRIWA research project M510.

References

Arroyo, M & Gens, A 2021, *Computational Analyses of Dam I at the Corrego de Feijao Mine in Brumadinho*, report for Vale S.A.

Abdulnabi, A, Amoako, K, Moran, D, Vanadara, K, Aldaeef, AA, Esmaeilzadeh, A, … & Simms, P 2022, 'Evaluation of candidate polymers to maximize geotechnical performance of oil sands tailings', *Canadian Geotechnical Journal*, vol. 59, no. 3, pp. 359–371.

Beier, N, Wilson, W, Dunmola, A & Sego, D 2013, 'Impact of flocculation-based dewatering on the shear strength of oil sands fine tailings', *Canadian Geotechnical Journal*, vol. 50, pp. 1001–1007.

Beveridge, A, Mutz, P & Reid, D 2015, 'Tailings co-disposal case study – art or science?', in R Jewell & AB Fourie (eds), *Paste 2015: Proceedings of the 18th International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 505–520, https://doi.org/10.36487/ACG_rep/1504_39_Beveridge

Cooling, DJ & Beveridge, A 2015,' Use of Rheomax ETD technology to thicken bauxite reisdual slurry during Super Thickener bypass', in AB Fourie & RJ Jewell (eds), *Paste and Thickened Tailings - A Guide*, 3rd edn, Australian Centre for Geomechanics, Perth, pp. 311–312.

Fanni, R, Reid, D & Fourie, AB 2022, 'Effect of principal stress direction on the instability of sand under the constant shear drained stress path', *Geotechnique*, https://doi.org/10.1680/jgeot.22.00062

Fourie, AB & Reid, D 2014, 'Assessing the post-liquefaction shear strength of thickened tailings in the design stage a review and update', in R Jewell, AB Fourie, PS Wells & D van Zyl (eds), *Paste 2014: Proceedings of the 17th International Seminar on Paste and Thickened Tailings*, InfoMine, Vancouver, pp. 429–444.

Gholami, R & Simms, P 2015, 'Shear behaviour in element testing of polymer amended mature fine tailings', *Proceedings of the 68th Canadian Geotechnical Conferenc*e, Canadian Geotechnical Society, Richmond.

Jeeravipoolvarn, S, Scott, JD & Chalaturnyk, RJ 2009, 'Geotechnical characteristics of laboratory in-line thickened oil sands tailings', *Proceedings of the Tailings and Mine Waste 2009 Conference*, University of Alberta Geotechnical Centre and Oil Sands Tailings Research Facility, Edmonton, pp. 813–828.

Jefferies, M & Been, K 2015, *Soil Liquefaction: A Critical State Approach*, 2nd edn, CRC Press, Boca Raton.

Jefferies, M, Morgenstern, NR, Van Zyl, DV & Wates, J 2019, *Report on NTSF Embankment Failure, Cadia Valley Operations*, report for Ashurst Australia.

Manzotti, A, Van Impe, PO, Van Impe, WF & Fratalocchi, E 2014, 'Impact of flucculants on the stress-strain behaviour of dredged sediments', *Proceedings of the 7th International Congress on Environmental Geotechnics*, Engineers Australia, Melbourne, pp. 650–656.

Mmbando, E, Fourie, A, Reid, D, O'Loughlin, C, Gao, J & Wang, Y 2022, 'Residual strength based on CPT sleeve friction and a constant volume ring shear device', *Proceedings of the Tailings and Mine Waste 2022 Conference*, Civil & Environmental Engineering Department, Colorado State University, Denver.

Mmbando, E, Fourie, AB & Reid, D 2023, 'Mechanics of an iron ore tailings exhibiting transitional behaviour', *Geotechnical and Geological Engineering*, vol. 799.

Morgenstern, NR, Vick, SG, Viotti, CB & Watts, BD 2016, *Fundão Tailings Dam Review Panel: Report on the immediate causes of the failure of the Fundão Dam*.

Reid, D & Boshoff, J 2015, 'Stability of a proposed steepened beach', in R Jewell & AB Fourie (eds), *Paste 2015: Proceedings of the 18th International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 181–194, https://doi.org/10.36487/ACG_rep/1504_12_Reid

Reid, D, Fanni, R & Fourie, A 2023, 'Discussion of "Mechanism of failure of the Mount Polley Tailings Storage Facility" by Zabolotnii, E, Morgenstern, NR and Wilson, GW', *Canadian Geotechnical Journal*, in press.

Reid, D, Fanni, R & Kulessa, M 2015, 'Cyclic and post-cyclic behaviour of four Australian tailings', *Proceedings of Tailings and Mine Waste Management for the 21st Century*, Australasian Institute of Mining and Metallurgy, Carlton, pp. 207–214.

Reid, D & Fourie, A 2017, 'Effects of polymer treatment on undrained strengths and cyclic behavior of a low-plasticity slurry', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 143, no. 04017007.

Reid, D & Fourie, A 2018a, 'Centrifuge assessment of the effects of polymer treatment on penetrometer response', *International Journal of Physical Modelling in Geotechnics*, vol. 18, pp. 240–252.

Reid, D & Fourie, AB 2018b, 'Geotechnical effects of polymer treatment on tailings – state of knowledge review', in RJ Jewell & AB Fourie (eds), *Paste 2018: Proceedings of the 21st International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 263–276, https://doi.org/10.36487/ACG_rep/1805_21_Reid

Reid, D & Fourie, AB 2015, 'Effects of shear on the behaviour of polymer-treated slurries', *Proceedings of Tailings and Mine Waste Management for the 21st Century*, Australasian Institute of Mining and Metallurgy, Carlton, pp. 215–224.

Reid, D & Fourie, AB 2016, 'Laboratory assessment of the effects of polymer treatment on geotechnical properties of low plasticity soil slurry', *Canadian Geotechnical Journal*, vol. 53, pp. 1718–1730.

Reid, D, Fourie, AB, Ayala, JL, Dickinson, S, Ochoa-Cornejo, F, Fanni, R … & Suazo, G 2021, 'Results of a critical state line test round robin program', *Géotechnique*, vol. 71, pp. 616–630.

Riley, TC, Reid, D & Utting, L 2015, 'Polymer-modified tailings deposition – ongoing testing and potential storage efficiency opportunities', in R Jewell & AB Fourie (eds), *Paste 2015: Proceedings of the 18th International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 139–152, https://doi.org/10.36487/ACG_rep/1504_09_Riley

Robertson, PK, de Melo, L, Williams, DJ & Wilson, GW 2019, *Report of the Expert Panel on the technical causes of the Failure of Feijão Dam I*.

Robertson, PK, Wride, CE, List, BR, Atukorala, U, Biggar, KW, Byrne, PM … & Zavodni, Z 2000, 'The CANLEX project: summary and conclusions', *Canadian Geotechnical Journal*, vol. 37, pp. 563–591.

Sheeran, DE & Krizek, RJ 1971, 'Preparation of homogenous soils samples by slurry consolidation', *Journal of Materials*, vol. 6, no. 2, pp. 356–373.

Shipton, B & Coop, MR 2015, 'Transitional behaviour in sands with plastic and non-plastic fines', *Soils and Foundations*, vol. 55, pp. 1–16.

Stark, TD & Contreras, IA 1996, 'Constant volume ring shear apparatus', *Geotechnical Testing Journal*, vol. 19, no. 1, pp. 3–11.

Xu, L & Coop, MR 2017, 'The mechanics of a saturated silty loess with a transitional mode', *Géotechnique*, vol. 67, pp. 581–596.

Yao, Y 2012, 'The effect of flocculant on the geotechnical properties of mature fine tailings: an experimental study', *Proceedings of the Third International Oil Sands Tailings Conference*, University of Alberta Geotechnical Center and Oil Sands Tailings Research Facility, Edmonton, p. 1–16.

Zabolotnii, E, Morgenstern, NR & Wilson, GW 2022, 'Mechanism of failure of the Mount Polley tailings storage facility', *Canadian Geotechnical Journal*, vol. 59, no. 8, https://doi.org/10.1139/cgj-2021-0036

Znidarcic, D, Adkins, S, Utting, L & Catling, M 2015, 'Rheomax ETD technology, a laboratory study of application performance and associated geotechnical characteristics for polymer assisted tailings deposition of oil sands MFT', Tailings and Mine Waste 2015, The University of British Columbia, Vancouver.