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Slurry Deposition Method For Reconstituting Specimens For Triaxial And Consolidation Tests

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SUMMARY: It is always challenging to obtain in situ engineering properties of cohesionless soils and coarse mine tailings in the laboratory due to difficulties to preserve undisturbed samples or replicate factors such as density, fabric, and stress/strain history. Field frozen techniques have been developed over the years giving satisfactory results, but they are far from being practical considering their complexity, cost and troublesome procedures. Reconstitution methods are usually the preferred choice and several options exist for specimen preparation. In this paper a special case of the water pluviation technique, called the slurry deposition method is reported and used to determine shear strength and consolidation properties of a fine sand tailings with high silt content. Reasons for selecting this method are various: first of all, underwater settling conditions better simulate tailings deposit formation; secondly, the technique also minimizes or eliminates particle segregation; thirdly, higher initial degrees of saturation can be obtained; lastly, slurry deposition specimen preparation requires simple equipment. For triaxial testing, a specimen was prepared using a split mold with a vacuum device for membrane stretching. Two solids contents were used for specimen preparation resulting in relative densities around 30% and 60%. Maximum backpressure of 450 kPa was enough to get B-values higher than 96%. Altogether five undrained and one drained triaxial tests were performed at effective confining stresses of 50 kPa. Results have shown consistency regarding stress-paths and stress-strain behaviours. Similarly, specimen preparation was also undertaken for one-dimensional consolidation tests using incremental load. Specimens were also produced by the slurry deposition method, resulting in soil elements with relative densities in the range of 38 to 60%. Consolidation results showed comparable compressibility indexes, irrespective of initial conditions. It is worth noting that the observed variable initial densities (or void ratios) seem to be strongly related to initially different slurry solids content, since the technique was the same in all cases. This finding was also observed in the triaxial specimens. Summing up, overall feasibility of a slurry deposition method for parameter determination of cohesionless soil with high solids fines content has been demonstrated. This technique, that reportedly emulates soil elements' in situ conditions, can provide more options for studies and designs of geotechnical structures sitting on tailings deposits such as tailings storage

facilities with upstream raises or the potential placement of thickened tailings on top of existing tailings storage facilities.

KEYWORDS: specimen reconstitution; slurry deposition; cohesionless soils; laboratory testing.

1 INTRODUCTION

Throughout the years, several techniques of specimen reconstitution have been developed to simulate in situ characteristics of cohesionless soils formed in natural environments, also including man made hydraulic fills and mine tailings deposits. Practices for specimen reconstitution more commonly used are moist tamping, air (dry) pluviation, and water (or wet) pluviation (or sedimentation) with its variants such as slurry deposition (Carraro and Prezzi, 2008). Comparisons of these techniques were made by several researchers (Carraro and Prezzi, 2008; Ghionna and Porcino 2006; Hoeg et al. 2000; Vaid et al. 1999). They found that it is questionable to use moist tamping to assess liquefaction, regardless of test loading (static, cyclic, triaxial, simple shear…) and that wet pluviation results are very close to results of undisturbed samples of in-situ fluvial and hydraulic fills. However, less noticeable differences between methods were observed at higher strains, towards the critical state.

Aimed at application of liquefaction studies of tailings deposits formed by hydraulic disposal, this research investigated specimen reconstitution procedures to obtain more realistic field material behaviour without having to recur to expensive and troublesome in-situ ground frozen techniques. Based on the literature, a decision was made to use the slurry deposition (SD) method which has been shown to be superior to the conventional wet pluviation techniques to deal with materials containing fines, as often occurs with mine tailings.

The slurry deposition technique embodies some desirable features in terms of field fabric simulation, avoidance of material segregation, and provision of initial saturation (Carraro and Prezzi, 2008). The technique allows some flexibility regarding initial void ratio range, seemingly related to slurry solids content, and material type (grading).

The slurry deposition method chosen in this research is a development of the original work of Carraro and Prezi (2008) with suitable modifications. For demonstration purposes the technique was used within standard testing routines of one-dimensional consolidation and triaxial compression tests.

2 MATERIAL AND EXPERIMENTAL METHODS

2.1 Silty sand tailings

Samples were collected from a TSF tailings beach of a gold mine in Kalgoorlie, Western Australia. The material contained significant salt content, which was removed due to potential for equipment corrosion. Salinity was measured indirectly through electrical conductivity in water solution, and results are 11.3 g/l (slurry at 50% of solids content by mass) and 18.1 g/l (slurry at 65% of solids content by mass).

2.2 Basic Characterization

The particle size distribution test was executed in accordance with ASTM 1289.3.6.3 and ASTM 1289.3.6.1, using hydrometer and sieve analyses. As a result, this non-plastic material presented 52% sand (fine), 38% silt and only 10% clay size particles. Additionally, this silt sand sample was tested for specific gravity (G_s)

giving a value of 2.85.

2.3 Limiting void ratios

Limiting void ratios were assessed by three different methods, one for minimum void ratio and two for maximum void ratio. Minimum void ratio was determined according to ASTM standard D4253-00, method 1A, with oven-dried soil and an electromagnetic vertically vibrating table. In order to determine maximum void ratio, both ASTM D4254 method B and ASTM D4254 method C were used for comparison.

It is important to note that samples with high silt content such as the one presented in this paper (48%) set an unprecedented condition to the original slurry technique and also to apply the standard ASTM limiting void ratio procedures (fines up to 15%).

2.4 Specimen preparation

Soil element specimens for one-dimensional consolidation and triaxial tests were recreated using a reconstitution technique for sand soils with fines as suggested by Carraro & Prezzi (2008), with suitable modifications and additions.

The materials used in this preparation were a 69 mm diameter acrylic cylindrical tube; two rubber stoppers, one with a valve attached in the centre, two porous stone discs, filter papers, deaired water, dry tailings, vacuum chamber, and an analytical mass balance.

Description of specimen preparation is as follows:

(1) Weigh enough dry soil to achieve a target solids content and a suitable soil column before specimen trimming.

(2) Prepare a homogenous mix (slurry) of dry soil/deaired water according to desired solids content and cylinder height.

(3) Place slurry in the vacuum chamber until no air bubbles can be seen on surface of the mixture.

(4) Close one end of the cylinder with one rubber stopper (bottom) and gently transfer the slurry into the cylinder. In first tests, a spoon was used to place the mixture inside the cylinder whereas in later tests the transfer was performed using a half PVC tube, channelling the flow, and a spoon.

(5) Complete the cylinder volume, if it is necessary, then add deaired water with care so no air bubbles are entrapped inside.

(6) Close the cylinder with the superior rubber stopper, the one with a small tube and a valve, and top up the water in the tube with deaired water until full and then close the valve.

(7) Turn the cylinder upside down continuously for 20 minutes. Check for material lumps stuck to the stoppers or the tube wall and also for bubbles during this procedure. For the former, gently tap the cylinder wall with a rubber hammer, and for the latter, the valved stopper should be removed and the mixture be topped up with deaired water to expel any bubbles. Then, replace the top stopper and resume inversion procedure.

(8) Once the mix is homogenous, remove the superior rubber stopper after opening the valve, and top up the mixture with deaired water if required. Then place a saturated porous stone and a filter paper on the cylinder full of mixture.

2.4.1 Consolidation specimen preparation

Specimen preparation as detailed previously is continued and the ensuing steps are performed to obtain one-dimensional consolidation specimens. Additional devices are required, such as a consolidometer base, specimen ring and collar ring.

(1) Place consolidometer base upside down on top of the cylinder, as seen in Figure 1. Then turn back the set into cell normal position, leaving cylinder upside down. Allow the set to rest for a period of time (30 minutes minimum), until the solids in

the mix have settled and soil has piled up with a height well above the specimen height including its collar.

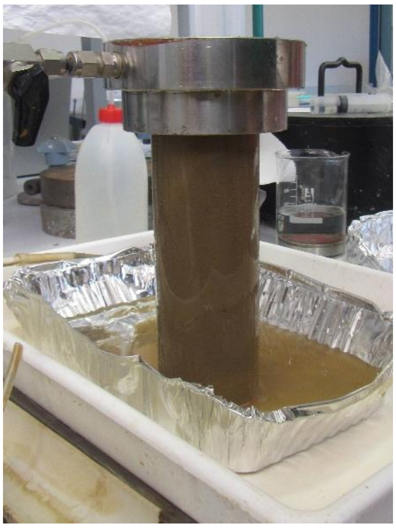

Figure 1. Consolidation test specimen preparation by slurry deposition

(2) Slide specimen ring down the cylinder and so too the collar ring. Remove rubber stopper that is sitting on top of the cylinder and syphon off the cleared water. Then, remove the cylinder.

(3) After removal of the cylinder, the material settles and piles up, forming a soil column. Allow the set to rest for a few minutes, start the levelling off operation at the collar ring top, and then at the specimen ring top. During specimen trimming, take three soil subsamples for moisture content determination. Always allow resting time between trimming stints for any pore water pressure dissipation to take place to avoid channelling flow and sand boils.

(4) Place the porous stone and filter paper. Clean specimen ring, then place the loading cap.

(5) From this point on, follow procedures of conventional one-dimensional consolidation test.

2.4.2 Triaxial specimen preparation

Completion of specimen preparation for triaxial tests is described next. Additional fittings are required such as split mold, collar ring, latex membrane, rubber O-rings, and vacuum source, besides triaxial base and triaxial chamber. The procedure differs from the one described by Carraro and Prezzi (2008). The new development was devised after several non-satisfactory results following the original procedure. The key point for success was to follow the same procedure used in step (1) for one-dimensional consolidation specimen preparation described hereinbefore. In the Carraro and Prezzi (2008) method, the cylinder tube is turned upside down instead of the base. In that case, one has to rely on porous stone and paper filter sandwich for perfect sealing of the system, which has proven difficult to obtain.

The complete procedures for reconstituting specimens preparation in triaxial tests are as follows:

(1) Fix latex membrane to base platen with two rubber O-rings. Assemble split mold, seating it on base platen. Fold membrane over the split mold rim. Apply vacuum to split mold in order to get perfect contact between membrane and split mold internal wall due to suction.

(2) Place base and split mold set upside down on top of the acrylic cylindrical tube filled with soil mixture. This step is similar to the one used to form consolidation specimens.

(3) Turn back the set into triaxial base normal position, leaving the cylinder upside down as presented in Figure 2.

(4) Top up with deaired water the gap between cylindrical tube and split mold.

(5) Open drainage lines in the triaxial base to expel any entrapped air, and refill that gap with water, establishing water connection between slurry and saturated drainage lines of the triaxial base and base platen. Replace any water lost in this process while filling the gap.

(6) Allow the set to rest for a period of time, until the solids in the mix has settled and a soil

column with sufficient height is identified with its top well above the specimen height including its collar.

Figure 2. Triaxial test specimen preparation by slurry deposition

(7) Slide the collar ring down. Remove the rubber stopper that is sitting on top of the cylinder and syphon off the cleared water. Then, remove the cylinder.

(8) After removal of the cylinder, material collapses and soil settles, forming a soil column. Allow the set to rest for a few minutes.

(9) Start the levelling off operation at the collar ring top, and then at split mold top. During specimen trimming, separate three soil subsamples for moisture content determination and always allow some resting time for any pore water pressure dissipation to take place to avoid channelling flow and sand boils.

(10) Place the porous stone and filter paper on the specimen top. Clean the folded part of the membrane, place the top cap and connect it to one of the drainage lines and finally roll over the membrane onto the top cap, fixing the set with two O-rings.

(11) Apply back pressure of 20 kPa in order to keep specimen shape once mold is removed. From this point on, follow procedures of conventional triaxial test.

2.5 One-dimensional consolidation and triaxial compression tests

Tailings consolidation properties were determined using incremental loading according to ASTM standard D2435/D2435M, and its soil shear strength were obtained by performing isotropically consolidated undrained and drained triaxial tests following ASTM D4767/D7181, respectively.

3 RESULTS

3.1 Limiting void ratios

Tests performed on the silty sand tailings resulted in a minimum index void ratio of 0.543 and maximum index density of 1.935 g/cm^3. For maximum index void ratio, two independent methods produced close results. The result of the method B was adopted in this paper, giving a maximum index void ratio of 1.015 and a minimum index density 1.479 g/cm^3.

3.2 Consolidation tests

Specimens produced by the slurry deposition method resulted in elements with relative densities in the range of 38% to 60% as shown in Table 1. It is worth noticing that the observed variable initial densities (or void ratios) seem to be strongly related to initially different slurry solids content, since the technique used was the same in all cases.

Table 1. Information on consolidation soil specimens

	Test 1	Test 2	Test 3
Initial void ratio	0.73	0.834	0.845
Nominal slurry solids content	70%	65%	62%
Initial relative density	60%	38%	36%

As for the consolidation results shown in Figure 3, the test have shown typical sand compressibility curves and comparable compressibility indices. Recorded data were obtained using two sources of measurement, lvdt readings and dial extensometer readings, which were consistent with one other.

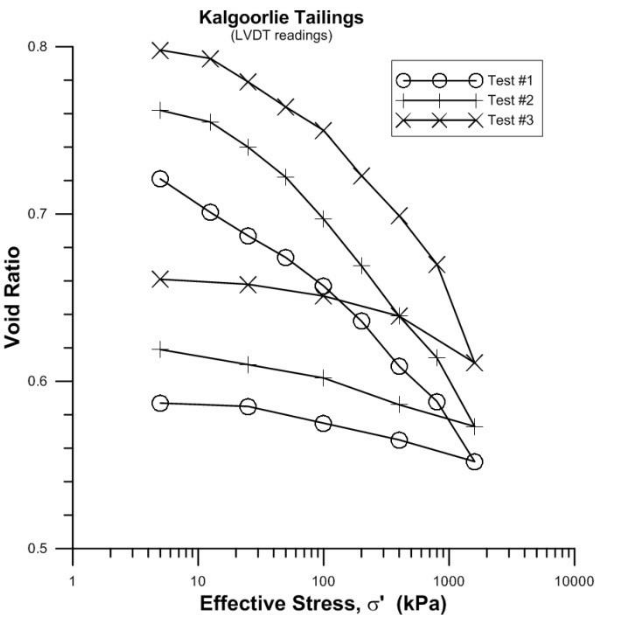

Figure 3. One-dimensional consolidation results on reconstituted specimens by slurry deposition – ldvt readings

Settlement stabilization in each stage of incremental loading occurred typically in a short period of time, requiring less than one hour. The unloading stabilization occurred even faster, within 20 minutes at maximum.

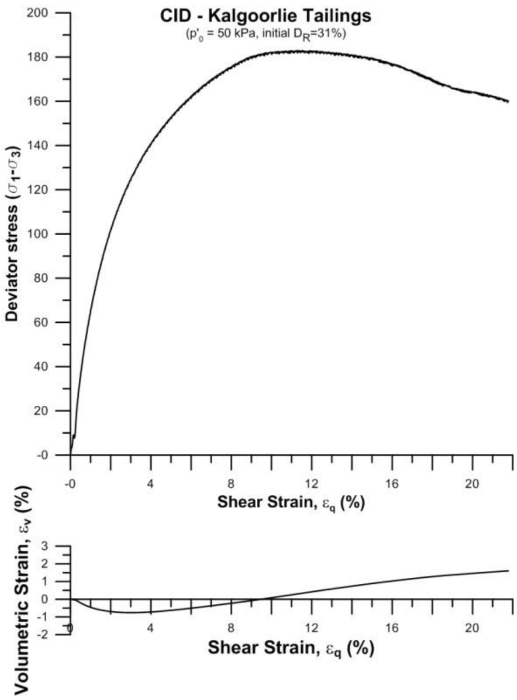

Figure 4. Typical consolidated drained triaxial result with slurry deposition specimen technique

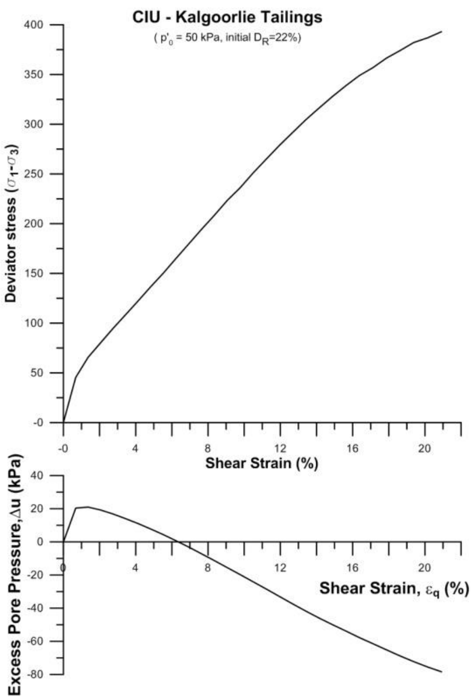

Figure 5. Typical consolidated undrained triaxial with slurry deposition specimen technique

3.3 Triaxial tests

Static undrained and drained consolidated triaxial tests were conducted on reconstituted specimens using the slurry deposition method. Upon specimen preparation, saturation was obtained by seepage flow at a low hydraulic gradient, followed by incremental back pressure stages. B-values around 0.96 or higher were obtained for back pressure of 450 kPa. The specimen was then isotropically consolidated to 50 kPa. Test shearing rate was established as 0.24 mm/min, based on consolidation data, until a deformation of 20 % axial strain was reached, which took approximately two hours.

Figures 4 and 5 show typical shear-strain and volumetric strain or excess pore pressure behaviour for drained and undrained axial compression triaxial tests, respectively. It is apparent that in both tests no strain-softening behaviour was observed as would likely occur using air pluviation and moist tamping techniques, especially for the looser specimen (Carraro and Prezzi 2008). This dilative behaviour disregards any liquefaction potential. Similar findings were also reported by other researchers who have concluded that specimens produced by slurry deposition are prone to exhibit a more "dense" pattern independently if the particle sedimentation occurred as the loosest manner (Yamamuro and Wood 2004).

4 DISCUSSION

The effectiveness of the slurry deposition technique to produce non-segregating specimens relies on a proportional mix of small amounts of water and larger solids particles quantity (high solids content) in such a way that proximity between particles limits relative movement between them during sedimentation, regardless of any difference in size or density (so particle segregation does not occur, unlike conventional water pluviation). This is true especially at the bottom of the column during specimen preparation. In this respect, Wood et al. (2008) executed particle size distributions of triaxial specimen layers prepared by slurry deposition and discovered almost exactly the same particle size distribution in the layers. This point is essential to accurately simulate field conditions and prove the applicability of the method.

The slurry deposition method provides some degree of flexibility in terms of specimen density and void ratio. Results presented in Table 1 suggest a correlation between initial solid contents and void ratio. This finding was also observed in triaxial specimen preparation. In addition, Kuerbis and Vaid (1988) suggest to apply pressure on the top platen and vibrate the base of the triaxial in order to obtain densified specimens.

The particular way in which soil particles in solution are deposited at the bottom of the specimen in the SD method also plays a crucial role in terms of structural arrangement (fabric), a feature common to water pluviation technique, and essential for realistic assessment of liquefaction potential.

5 CONCLUSIONS

In this paper a slurry deposition technique was applied to determine shear strength and consolidation properties of fine sand tailings with high silt content (48%). This grading composition set an unprecedented condition for the original slurry technique and also to apply standard ASTM limiting void ratio procedures. The proposed technique results in a homogenous specimen that simulates a tailings deposit formation, according to the literature. Moreover, high initial degrees of saturation can be obtained from this method and the process is relatively simple.

Consolidation curves show typical sand behaviour and practically the same compressibility index for repeated tests. Triaxial tests performed on specimens prepared with this slurry deposition technique have shown strain hardening and dilative behaviour, even with specimens with relatively high void ratios. These results may question potential liquefaction assessment often obtained through reconstituted techniques using moist tamping.

The overall feasibility of the slurry deposition method for parameter determination of cohesionless tailings with high solids fines content has been demonstrated. This technique, that reportedly emulates in situ conditions, can bring more options for studies and designs of geotechnical structures sitting on tailings deposits such as TSFs with upstream raises or placement of thickened tailings onto existing TSFs.

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