Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-439

Reconstitution of samples for the study of mechanical behaviour of sulphide-rich soils

Reconstitution des échantillons pour l'étude du comportement mécanique des sols riches en sulfures

N. Garcia*, P. Gunnvard, Q. Jia, J. Laue
Luleå University of Technology, Luleå, Sweden

**nelson.garcia@ltu.se*

ABSTRACT: Sulphide-rich soil, a prevalent soft alluvial type along the Baltic Sea coast, is characterised by its sulfur content, low strength, high compressibility and significant organic components. Common practice involves replacing this soil with more resilient subgrade materials; however, excavated sulphur-rich soil necessitates to be treated as environmentally hazardous, due to its oxidation potential, leading to increased construction expenses. If instead, sulphide-rich soil is going to be used as subgrade, it becomes crucial to define its cyclic mechanical properties. This requires representative samples, which may not always be available through conventional undisturbed sampling methods. In this paper, the slurry deposition method was adopted to generate reconstituted samples of sulphide-rich soil for static triaxial testing. The method provided consistent samples and captured the characteristics of the natural soil. The triaxial results are the first step towards the understanding and definition of the cyclic behaviour of sulphide-rich soil.

RÉSUMÉ: Les sols riches en sulfures, un type alluvial mou prévalent le long de la côte de la mer Baltique, se caractérisent par leur teneur en soufre, leur faible résistance, leur grande compressibilité et leur teneur significative en matières organiques. La pratique courante consiste à remplacer ce sol par des matériaux de sous-fond plus résilients. Cependant, le sol riche en soufre excavé doit être traité comme dangereux pour l'environnement en raison de son oxydation, ce qui entraîne des coûts de construction accrus. Si, au contraire, le sol riche en sulfures doit être utilisé comme sous-fond, il devient essentiel de définir ses propriétés mécaniques cycliques. Cela nécessite des échantillons représentatifs, qui ne sont pas toujours disponibles par le biais de méthodes d'échantillonnage classiques non perturbées. Dans cet article, la méthode de dépôt de boue a été adoptée pour générer des échantillons reconstitués de sol riche en sulfures en vue d'essais triaxiaux statiques. Cette méthode a fourni des échantillons cohérents et a capturé les caractéristiques du sol naturel. Les résultats triaxiaux constituent la première étape vers la compréhension et la définition du comportement cyclique du sol riche en sulfures.

Keywords: Slurry deposition; sulphide-rich soil; triaxial testing.

1 INTRODUCTION

The construction of roads and railways in regions characterised by sulphide-rich soil deposits, particularly prevalent along the Baltic coastal areas of Sweden and Finland, presents a pressing geotechnical challenge. This unique fine-grained soil is known for its soft properties and high natural void ratio, with voids containing high amounts of water, organic matter, and sulphides, resulting from its anaerobic sedimentation during the last glaciation in tranquil brackish estuaries (Pousette et al., 2008). The soft nature of sulphide-rich soil, defined by low undrained strength and high compressibility and viscosity (e.g. Yu, 1993; Westerberg et al., 2005), implies significant obstacles to geotechnical structures leading to a common practise of excavating and replacing this soil. In addition, the sulphide-rich sediment produces acidic leachate when oxidised. Hence, excavated sulphide-rich soil is treated as environmental hazardous waste, increasing project costs and transportation emissions.

Recent advancements in soil stabilization and reinforcement techniques offer potential solutions for utilising sulphide-rich soil as a subgrade material. The subgrade of a road or railway embankment may not require a high bearing capacity, but it is subjected to high-cycle loads, characterised by large numbers of cycles with small amplitudes. Accurate predictions of deformation and pore pressure development are needed to ensure the long-term performance of the transportation network. However, the cyclic behaviour of sulphide-rich soil, with its unique properties, is not well studied.

Representative samples are needed to define the behaviour of a soil by laboratory testing. The softness of sulphide-rich soil prevents, in most cases, undisturbed sampling. Making conventional sampling techniques, such as piston sampling, impractical or potentially disruptive. Disturbed samples can be reconstituted into representative samples instead. The slurry deposition method was initially devised for the reconstitution of sandy soils with fines. The method can also be applied to reconstitute silts and clays (Liu et al., 2017). However, its applicability on the reconstitution of organic fine-grained soils, such as sulphide-rich soil, needs to be investigated.

The aim of the research project is to investigate the cyclic behaviour of sulphide-rich soil and provide valuable insights for the design and construction of roads and railways in regions abundant with this distinctive soil type. Prior to cyclic triaxial testing, it is necessary to conduct static triaxial testing to obtain basic strength parameters of the soil and establish optimal test conditions. This paper covers the application and suitability of the slurry deposition method for the static triaxial testing of reconstituted samples of sulphide-rich soil.

2 SAMPLE RECONSTITUTION

The reconstitution of samples is a common practise in laboratory investigations of silts. Various techniques have been proposed for this purpose, such as moist tamping methods, water or air pluviation, and slurry deposition (Ladd, 1978; Kuerbis and Vaid, 1988; Carraro and Prezzi, 2008). Evaluations of the merits and drawbacks of these different reconstitution techniques can be found in Bradshaw and Baxter (2007) and Reid et al. (2022). When dealing with sulphide-rich soil, some challenges arise: the inability to dry the soil due to cementation and potential oxidation, the need for homogeneous reconstitution to the desired conditions, and disturbances by preparing the sample directly within the triaxial cell. The most fitting of the considered techniques, meeting all stipulated criteria, is the slurry deposition method. As the name suggests, the method involves consolidating the sample to the desired conditions starting from a slurry.

2.1 Soil Characteristics

The soil used for this study is a clayey silt, sourced from a landfill of freshly excavated soil from the Northern coastal area of Sweden. An overview of the basic parameters of the soil can be found in Table 1.

Table 1. Basic Soil Properties.

Property	
Clay Content	10 %
Silt Content	60 %
Sand Content	30 %
Organic Content	4 %
Specific Gravity	2.76
Water Content	40 %
Liquid Limit	33 %

2.2 Sample Preparation

The following equation by Liu (2017) is used to determine the amount of slurry needed for one sample,

$$m_{slurry} = (\pi \cdot h \cdot r^2) \cdot \rho_{dry} \cdot (1 + \omega_{slurry}) \quad (1)$$

where m_{slurry} corresponds to the mass of slurry to be poured, h is the height of the final sample, r denotes the radius of the final sample, ρ_{dry} corresponds to the target dry density, and ω_{slurry} is the water content of the slurry. Figure 1 shows the procedure followed for the sample reconstitution:

a) Assembly of the latex membrane, split mould, and bottom filter onto the triaxial base plate. Talc powder is applied to the mould exterior to prevent adhesion of the membrane.
b) Three strips of filter paper are placed inside the membrane to quicken the slurry consolidation.
c) A rubber support is fixed to the upper section of the split mould with two clamps.
d) An extension tube is inserted into the rubber support and fastened using the two clamps.
e, f) A funnel with an elongated nozzle is used to pour the predetermined m_{slurry}. As the slurry is gradually poured, the funnel is slowly raised with the nozzle end following the slurry surface.
g) A top filter and plug are positioned at the uppermost section of the extension tube. The consolidation process is initiated with a surcharge load atop the plug and vacuum pressure at the base. Both the surcharge and vacuum are maintained at pressures lower than the minimum confining pressure applied during the triaxial test. Water is added at the top to ensure that the sample remains fully saturated.
h, i) When the defined sample height h is reach, the surcharge load and vacuum pressure are removed, and the rubber support and clamps are detached. The soil sample is then cut at the top of the split mould. The part of the sample remaining in the extension tube is used to determine water content and soil density.
j) The prepared sample is mounted onto the triaxial apparatus following the standard procedure.

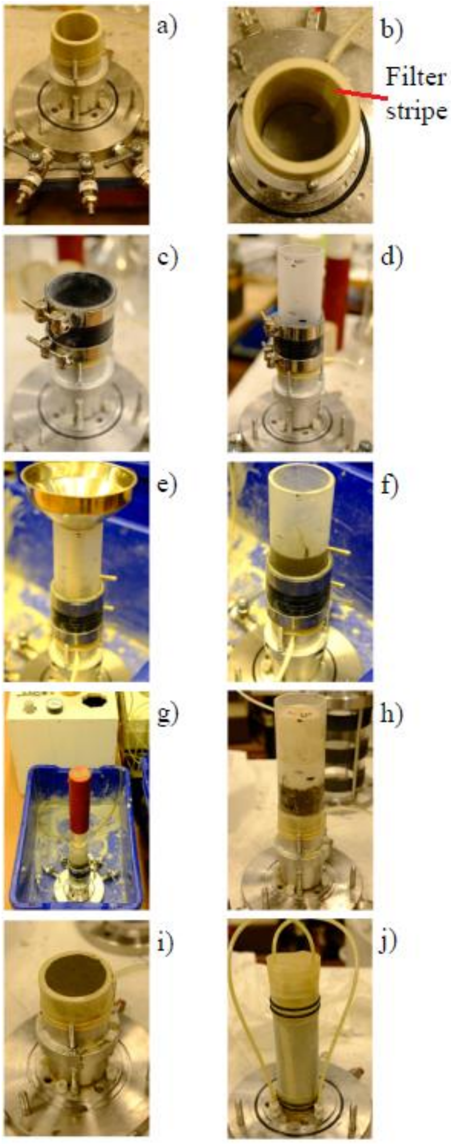

Figure 1. Steps for reconstitution of a sample by slurry deposition.

3 RESULTS

The presented results serve as an initial assessment to validate the suitability of the slurry deposition method for sulphide-rich soil. Four consolidated drained triaxial tests were carried out on reconstituted samples, with confining pressures of 30, 60, 100 and 200 kPa, respectively. The density, water content and void ratio of the four samples are shown in Figure 2. The samples exhibit a satisfactory level of homogeneity. The range of results from the reconstituted samples is in fact narrower than the relatively broad range in results obtained from testing undisturbed samples of this soil type.

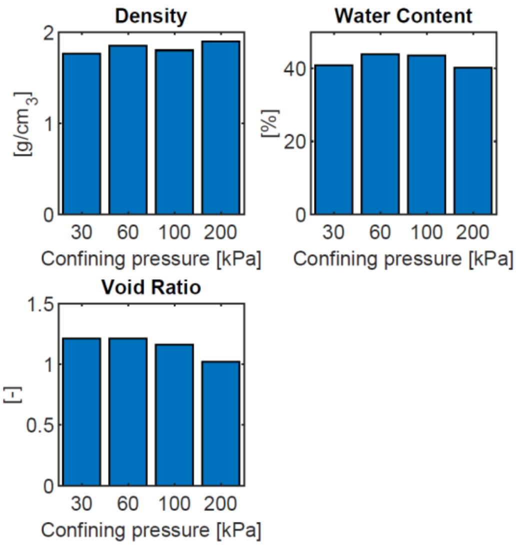

Figure 2. Measured density, water content and void ratio from the reconstituted samples for triaxial testing.

The triaxial test results are plotted in Figure 3 and 4. As the confining pressure increases, the samples exhibit failure at higher deviatoric loads, accompanied by a more distinct peak strength (Figure Figure 3a). Moreover, it is noteworthy that the failure of these samples takes place at high strains, undergoing significant consolidation while shearing, denoted by the large volumetric strains (Figure 3b), which is common for undisturbed samples (Yu, 1993). An indication of comparable behaviour between samples is the assymptotic tendency of the volumetric strains at failure around the same value (Lade, 2016). Also, the critical points utilized in deriving the critical state line (Figure 4) align well.

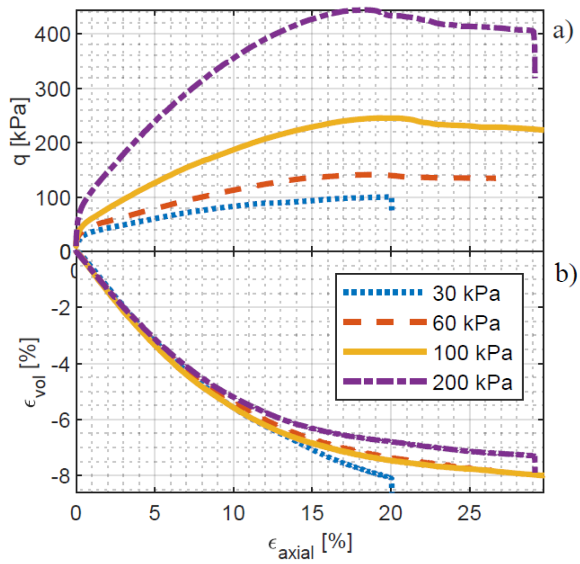

Figure 3. Results from the static triaxial tests: a) axial strain ϵ_{axial} vs deviatoric stress q, and b) axial strain ϵ_{axial} vs volumetric strain ϵ_{vol}.

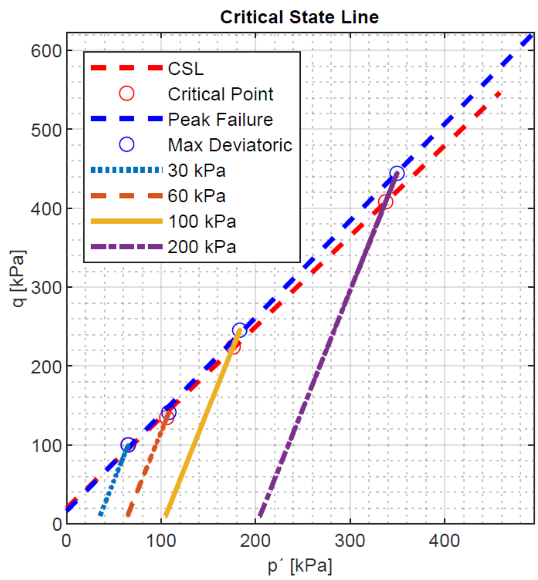

Figure 4. Derived critical state line (CSL) and peak failure line on the plane of deviatoric stress (q) and mean effective stress (p′).

4 CONCLUSION

The slurry deposition method was evaluated for generating reconstituted samples of sulphide-rich soil. Index property tests and consolidated drained triaxial tests were performed on reconstituted samples. The results show that the slurry deposition method not only yielded samples with remarkable homogeneity, both within and across multiple samples, but also provided the flexibility to influence sample density, allowing for a closer match to in-situ conditions. Triaxial testing of the reconstituted samples displayed the main typical characteristics of undisturbed samples, i.e. failure at large deformations and significant volumetric strain change. However, it is essential to acknowledge that the natural soil exhibits an array of anisotropies that cannot be replicated using this method.

Sulphide-rich soils are frequently observed to be overconsolidated, particularly in the uppermost strata of the deposit. Samples obtained through the slurry deposition method and isotropically consolidated in the triaxial are normally consolidated, as shown by the contractant behaviour of the tested samples. This condition does not pose a significant concern, as the targeted overconsolidation ratio can be reached by adding a second consolidation step in the triaxial test.

Based on the results of this paper, the slurry deposition method is a valuable tool for the reconstitution of sulphide-rich soil samples in geotechnical studies. To have a final verdict about the method, reconstituted sulphide-rich soil samples will be compared with undisturbed samples of the same source material.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support provided by funding agency Branschsamverkan i grunden (BIG). The project presented in this article is supported by the Swedish Transport Administration.

REFERENCES

Anantanasakul, P. and Kaliakin, V. N. (2012). Stress-strain and strength characteristics of silt-clay transition soils, *Journal of Geotechnical and Geoenvironmental Engineering*, 138(10), pp. 1257–1265. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000692.

Bradshaw, A. S. and Baxter, C. D. P. (2007). Sample preparation of silts for liquegaction testing, *Geotechnical Testing Journal*, 30(4), pp. 324–332. ASTM International https://doi.org/10.1520/GTJ10364J.

Carraro, J. A. H. and Prezzi, M. (2008). A new slurry-based method of preparation of specimens of sand containing fines, *Geotechnical Testing Journal*, 31(1), pp. 1–11. https://doi.org/10.1520/GTJ100207.

Kuerbis, R. and Vaid, Y. P. (1988). Sand sample preparation-the slurry deposition method, *Soils and Foundations*, 28(4), pp. 107–118. https://doi.org/10.3208/sandf1972.28.4_107.

Ladd, R. S. (1978). Preparing test specimens using undercompaction, *Geotechnical testing journal*, Vol. 1, pp. 16–23. http://doi.org/10.1520/GTJ10364J.

Lade, P. V. (2016). *Triaxial testing of soils*, 1st ed., Wiley Blackwell, Chichester, United Kingdom. https://doi.org/10.1002/9781119106616.

Liu, W., Tang, X. and Yang, Q. (2017). A slurry consolidation method for reconstitution of triaxial specimens, *KSCE Journal of Civil Engineering*, 21(1), pp. 150–159. https://doi.org/10.1007/s12205-016-0199-9.

Pousette, K., Eriksson, L. and Knutsson, S. (2008). Acidification properties of sulphide soil: a classification system based on leaching tests, In: *Proceedings of the 15th Nordic Geotechnical Meeting (NGM 2008)*, Sandefjord, Norway, pp. 415–422.

Reid, D., Fanni, R. and Fourie, A. (2022). Slurry deposition preparation method for tailings characterisation: history, debates, techniques and benefits, In: *Proceedings of the 8th International Conference on Tailings Management (Tailings 2022)*, Online conference.

Westerberg, B., Albing, D. and Larsson, R. (2005). Research on strength and deformation properties of Swedish fine-grained sulphide soils, In: *Proceedings of the 16th international Conference on Soil Mechanics and Geotechnical Engineering*, 2(1), pp. 623–626. https://doi.org/10.3233/978-1-61499-656-9-623.

Yu, Y. (1993). *Testing and modelling of silty and sulphide-rich soils*, PhD thesis, Luleå University of Technology, ISSN 0348-8373, 121 [print].