Stress state prediction numerical benchmarking exercise

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Introduction

The modelling of embankments using numerical stress-deformation techniques, while a part of geotechnical engineering analyses for some time, has undoubtedly increased over the past decade because of increased computing power, implementation of a more diverse range of constitutive models and, related to tailings engineering practice, the increased focus on slope stability after a series of tailings storage facility (TSF) failures.

While the numerical techniques applied to these problems are sophisticated, some significant uncertainties remain. One of these uncertainties is the difficulty in reliably predicting the in situ stress state (Geostatic stress ratio K_0, Lode Angle θ, stress ratio η, principal stress angle α) in numerical models simulating slopes. This stress state is a major factor in the assessment of whether a particular element of soil below a slope is at risk of "triggering" – i.e. reaching its instability stress ratio η_{IL}, and thus potentially undergoing rapid post-peak strength loss. However, different constitutive models, and even different calibrated inputs to the same model, can produce materially different predictions of the in situ stress state below slopes.

This benchmarking exercise aims to investigate some of these issues by providing a robust data set of triaxial element tests on a sandy silt tailings to the participants, and having them carry out numerical predictions for the behaviour of the same soil in the following types of tests:

- K_0-consolidated triaxial tests – i.e. axisymmetric, no lateral strain
- Hollow cylinder torsional shear (HCTS) tests using a drained simple shear module where the tested specimen is taken from an initial, low-stress, axisymmetric state to a final specified value of vertical effective stress and horizontal shear stress (τ_{vh}) while maintaining plane strain conditions.

The reference material for this exercise is a low plasticity sandy silt gold tailings, with the triaxial and HCTS tests undertaken on specimens having been prepared using loose moist tamping (MT) and "air-dried" (AD) sample preparation techniques, respectively, to target a range of initial void ratios. Duplicate tests will be carried out by the organisers to ensure the reliability of the laboratory test data used to compare to the predictions made by participants.

Participants of the program are tasked with predicting the final stress state that will develop at the end conditions specified for the tests. It is emphasised that participants are to predict these values numerically, using a model and parameters of their choice calibrated based on the provided laboratory reference data.

Calibration data provided

The following data will be provided electronically to participants in the program:

- Critical state line (CSL) and critical state friction ratio M_{tc} definition to be adopted by all participants. Although the selection of a CSL and M_{tc} may itself by considered a potential uncertainty in such a program, our intention is to focus on constitutive model prediction differences and/or more subtle "second order" calibrations of elasticity and plasticity parameters (for example) and their implications. Therefore, all participants are to use the same CSL and M_{tc} definition (that is, if the model they select for the exercise requires these as inputs).

- Digital data for a series of loose and dense, drained and undrained triaxial compression test data, including the tests used to infer the CSL tests and various other tests.
- Bender element tests across a range of mean effective stresses.
- Tests provided will have been prepared using both MT and AD techniques, to enable participants to prepare fabric/preparation-specific calibrations should they wish to.

All the data will be provided electronically through an online repository well in advance of the due date of predictions.

Predictions required

General

Four types of tests carried out by the organisers which the participants will be tasked with numerically simulation are as follows:

- 1A: Triaxial K_0 – MT sample preparation
- 1B: Triaxial K_0 – AD sample preparation
- 2A: HCTS drained simple shear – MT sample preparation
- 2B: HCTS drained simple shear – AD sample preparation

Initial stress conditions will be provided for each of these tests, and participants will be required to provide their predicted final stress conditions as per the "final condition" schematic and Table 1 as outlined below.

K_0 triaxial tests

K_0 triaxial tests will be carried out such that negligible radial deformation occurs during consolidation. The initial conditions for such a test, the final conditions that will be known to participants and those that are to be predicted are presented in Figure 1.

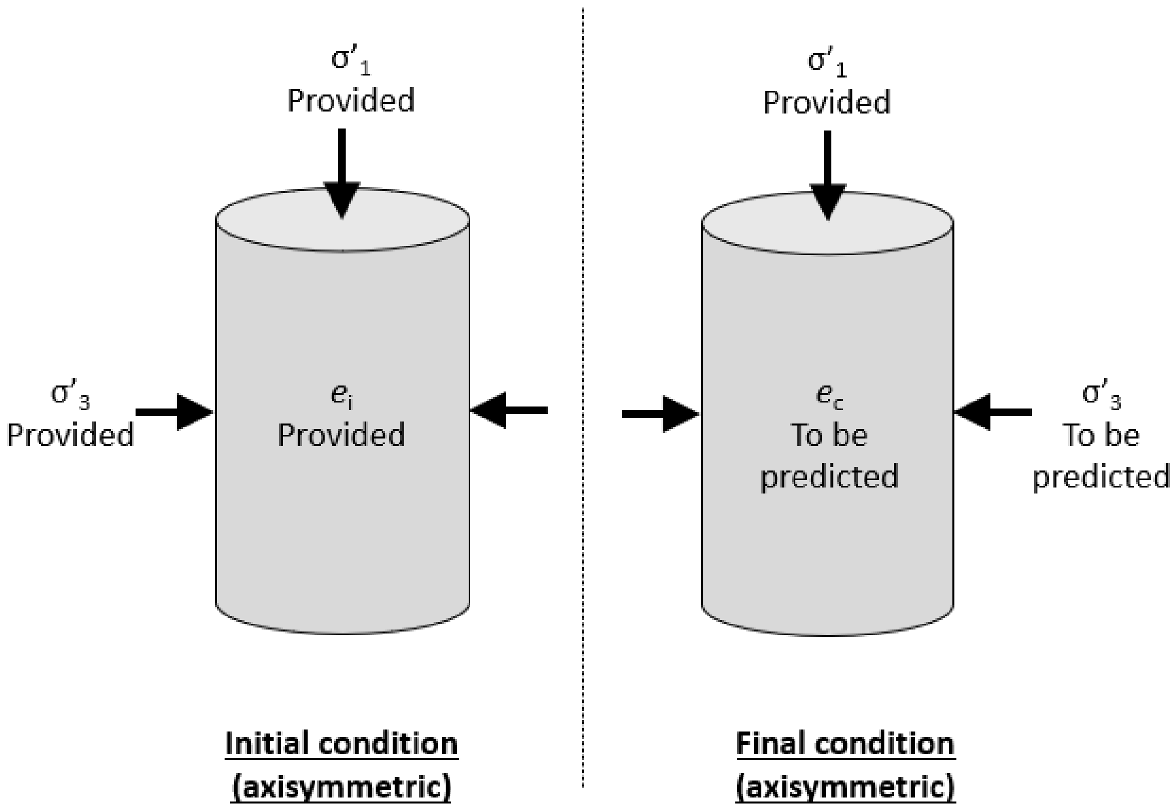

Figure 1: Triaxial K_0 test provided/required data schematic

The participants will be provided with the following information specific to the K_0 triaxial tests:

- Initial void ratio, e_i
- Initial stress conditions (σ'_1, σ'_2, σ'_3), which will be axisymmetric and relatively low initial stress (p'_i < 30 kPa)
- Final vertical effective stress
- Rate of pressure ramping used to achieve final target stresses

The process of "ramping" the stresses to the target values will be carried out at a rate sufficiently slow for drained conditions to prevail throughout the test based on our experience with the tailings, and evidence to this effect available based on post-ramping test behaviour if required/requested and included in the electronic data of the paper produced as part of this work.

Drained simple shear HCTS tests

A module has been developed at UWA to enable drained simple shear testings under plane strain conditions (i.e. $\varepsilon_2 = 0$) testing while ramping vertical effective stress σ'_v and/or τ_{vh}. This module allows a reasonable simulation of the path likely to be followed by an element of tailings deposited on a beach near the perimeter and then subsequently exposed to increasing stresses owing to the placement of additional layers of tailings and formation of a slope. A publication outlining the details of this test procedure is currently under preparation, showing evidence that plane strain conditions are maintained when in use.

The details of drained simple shear test planned is schematically prepared in Figure 2, along with the initial and final stress conditions. The initial state will be axisymmetric, and this will be followed by a plane strain consolidation process.

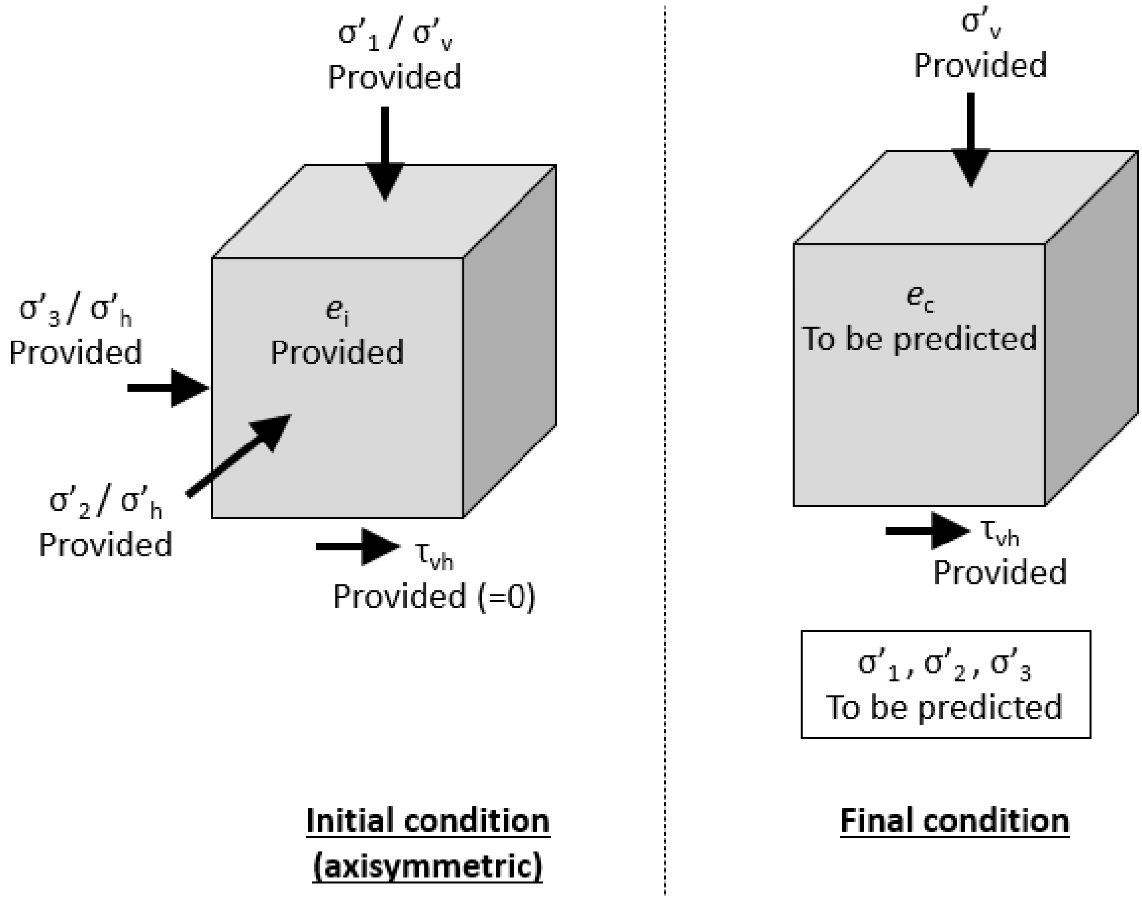

Figure 2: HCTS drained simple shear provided/required data schematic

The participants will be provided with the following information specific to the drained simple shear HCTS tests:

- Initial void ratio, e_i
- Initial stress conditions (σ'_1, σ'_2, σ'_3), which will be axisymmetric and relatively low initial stress (p'_i < 40 kPa)
- Final vertical effective stress
- Final horizontal shear stress τ_{vh}
- Rate of pressure ramping used to achieve final target stresses

The process of "ramping" the vertical effective and horizontal shear stresses to these values will be carried out at a rate sufficiently slow for drained conditions to prevail throughout the test based on our experience with the tailings, and evidence to this effect based on post-ramping test behaviour can be made available if required/requested.

Summary of initial test data and predictions information required

A summary of the relevant values that will be provided to participants at the commencement of each test are provided in Table 1, along with the values required to be numerically predicted. To be considered a valid entry to the program and to be included in the paper as a co-author, the participants are to supply the information required in Table 1 along with the following:

- Details on constitutive model used in their prediction.
- Calibrated input parameters for the constitutive model, for both AD and MT specimens.

Table 1: Initial and final conditions summary of known and unknown values for participants

<table>
<tr><th>Stress / state</th><th>Initial condition</th><th>Final condition</th></tr>
<tr><td colspan="3">K_0 triaxial tests</td></tr>
<tr><td>σ'_1</td><td>Provided</td><td>Provided</td></tr>
<tr><td>σ'_2 / σ'_3</td><td>Provided (axisymmetric test)</td><td>To be predicted</td></tr>
<tr><td>Void ratio (e_i / e_c)</td><td>Provided</td><td>To be predicted</td></tr>
<tr><td colspan="3">Drained simple shear HCTS tests</td></tr>
<tr><td>σ'_v</td><td>Provided</td><td>Provided</td></tr>
<tr><td>σ'_1</td><td>Provided (=σ'_v in initial conditions)</td><td>To be predicted</td></tr>
<tr><td>σ'_2</td><td rowspan="2">Provided (axisymmetric initial conditions)</td><td>To be predicted</td></tr>
<tr><td>σ'_3</td><td>To be predicted</td></tr>
<tr><td>τ_{vh}[1]</td><td>Provided (=0)</td><td>Provided</td></tr>
<tr><td>α</td><td>Provided (=0°)</td><td>To be predicted</td></tr>
<tr><td>θ</td><td>+30°</td><td>To be predicted</td></tr>
<tr><td>Void ratio (e_i / e_c)</td><td>Provided</td><td>To be predicted</td></tr>
</table>

Program dates

Provision of triaxial test data set: 1 November 2022

Provision of the final details on the K_0 triaxial and HCTS drained simple shear, to enable predictions to commence: 1 December 2022

Due date for predictions: 1 February 2023

Program proposed outcomes, publication, and authorship

The primary intended outcome of the current study is to be a journal paper. However, as there is no guarantee of publication given the peer-review process, we note the timeframe and final form of the publication cannot be reliably established at this time. Regardless of the final form of the publication, it is emphasised that it is intended for all data relevant to this work to be provided electronically as a supplement to the publication. The program organisers note that many scientific journals require electronic data or code to be provided, whereas (for reasons unclear to the organisers) this is not mandated in most geotechnical journals. However, we are strongly of the view that this should be mandated, and such data will be provided as part of the publication of the current work.

It is our intention for all participants to be co-authors of the work. As participants are likely to work in teams, it is envisaged that up to two participants for each entry can be co-authors to the work. However, this will be confirmed once we have an idea on total participant numbers. Participants will also need to indicate in writing that they did not compare their entry or process to other groups of participants prior to submission. The correspondence provided to this effect will be included in the electronic data package that accompanies the final publication. This can therefore enable multiple teams from the same organisation to participate and form separate independent entries, should there be such interest.

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[1] In HCTS literature and nomenclature, τ_{vh} is referred to as $\tau_{z\theta}$. In this program τ_{vh} is used as this is likely the most common general representation of horizontal shear stress in numerical analyses.

We note that while it is our intention to develop a final journal paper that all participants can agree on, it is conceivable that diverging opinions may make this difficult. As a first means to deal with this, if there is significant disagreement, we intend to structure the paper in a way that presents these different points of view. However, should even this prove unsuccessful, the participant organisers David Reid, Riccardo Fanni, and Andy Fourie have "final cut" on the document, and it will be for participants to decide if they are happy to proceed as co-authors on that basis.

It is likely that the synthesis of testing data and the development of a paper that satisfies most/all participants will require significant communication and iteration. Therefore, a project-specific Slack group will be created to facilitate this process in an efficient manner. Participating in this program means one has agreed to use this interface for project communication in the paper development stage, and that inefficient "reply-all chains" and synchronous verbal communication sessions will therefore be avoided.

Finally, there remains the possibility that despite the proposed steps we have outlined a that participant may still be dissatisfied with the outcomes of the testing and/or how the results compare to their numerical predictions. If such a situation develops, we are open to sharing the tailings material used in the program with another laboratory with experience carrying out such tests to perform confirmations. However, were such a situation to develop, the other laboratory (presumably affiliated with the participant raising such objections) would need to prioritise the tests as publication will not be delayed significantly for such confirmatory tests.

Note on ongoing related publications

As part of the development of the HCTS system to carry out these tests, two publications by the developers of the current program will be under review over the same period as the program dates listed above. It would likely be viewed as inappropriate, in the context of the proposed benchmarking exercise, if any of the participants were to have been anonymous reviewers of these publications. For example, such participants could be privy to information regarding some of the test results prior to other participants. Therefore, it is critical that participants to the current program indicate in writing, as part of their submission, that they had not been a reviewer of any papers submitted by the organisers of this program that dealt with our HCTS drained simple shear testing techniques.

Register your interest

If you wish to participate in this program, please email slope.stress.rr@gmail.com so you can be added to the project mailing list and kept up to date of future developments and data releases. Finally, questions posed to the organisers by participants will be continuously posted online at the following location, to ensure all participants are privy to the same information: https://docs.google.com/document/d/1HLD7XCyelPbq-vetetpgvELWlG4FZhd8LBXp5UoqFaQ/edit?usp=sharing