Numerical Verification of Tensile Stress Development in Highly Fractured Phyllite Characterised via Pressuremeter Test

Vérification Numérique du Développement du Stress de Traction Dans le Phyllite Fortement Fracturé Caractérisé par le Test du Pressuremeter

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ABSTRACT: The understanding of cavity contraction within a highly fractured rock mass requires reliable characterisation, which can be challenging since the fractured characteristics hinder the reliability of conventional testing methods. This leads to the use of in-situ pressuremeter testing (PMT) method. In this study, numerical interpretation of PMT results were done using 3D finite element modelling to generate a modelled material whose ability to carry tensile stress would then be subsequently verified. This paper presents a numerical modelling technique that enables the model to carry tensile stress from cavity contraction, which could potentially improve the reliability in simulating stresses development around tunnel cavities within a highly fractured geology.

RÉSUMÉ : La compréhension de la contraction de la cavité au sein d'une masse rocheuse très fracturée nécessite une caractérisation fiable, ce qui peut être difficile car les caractéristiques fracturées entravent la fiabilité des méthodes d'essai classiques. Cela conduit à l'utilisation de la méthode de mesure pressiométrique in situ (PMT). Dans cette étude, l'interprétation numérique des résultats de PMT a été effectuée en utilisant la modélisation 3D d'éléments finis pour générer un matériau modélisé dont la capacité à supporter une contrainte de traction serait ensuite vérifiée. Cet article présente une technique de modélisation numérique qui permet au modèle de supporter une contrainte de traction de la contraction de la cavité, ce qui pourrait améliorer la fiabilité dans la simulation du développement des contraintes autour des cavités du tunnel dans une géologie très fracturée.

KEYWORDS: numerical model, pressuremeter test, hardening soil, cavity contraction, highly fractured geology

1 INTRODUCTION

The understanding of cavity contraction phenomenon is essential for the assessment of stress changes around the cavity. This is evident in underground tunnel constructions, where the excavation causes stress-relief in the geology around the cavity. Generally, tunnels in soil could collapse due to the relatively low strength. This assumption was used to calculate normal stresses acting on pipe structures within soils (Pellet-Beaucour and Kastner, 2002). However, tunnels in rocks are more likely to self-stand due to the higher strength exhibited and the reported ability to carry tensile stresses (Haberfield, 1997; Haberfield and Johnston, 1986).

This study aims to verify a numerical modelling technique that enables a modelled rock mass to carry tensile stress when simulating cavity contraction, which may potentially improve the reliability of measuring arching effect in tunnels. This is essential for jacking force assessment in a pipe-jacking project, as arching effect reduces the effective normal stress on the pipes (Terzaghi, 1936).

The encountered geology consists of phyllite rock mass within Tuang Formation in Sarawak, Malaysia, which are described to be highly fractured (Tan, 1993) with most recoverable rock cores yielding Rock Quality Designation (RQD) values of zero. The RQD value represents the percentage length of intact rock cores measuring at least 100mm within a total cored length (Deere, 1989). The poor RQD values indicated the scarce supply of usable intact rock cores for conventional testing methods. Therefore, in-situ tests such as pressuremeter tests (PMTs) were used as alternatives since they do not require rock cores for testing.

The PMTs in this study were performed according to ASTM D4719 (2007), while the results were interpreted numerically (Phangkawira et al., 2016a; Phangkawira et al., 2016b) to create a modelled highly fractured phyllite for the subsequent verification exercise. The verification exercise was conducted to generate full tensile stress development in the model when simulating cavity contraction. The numerical model was generated using the commercial finite element package, PLAXIS 3D (Plaxis, 2013). The Hardening Soil Model (HSM) was used to simulate the behaviour of the highly fractured phyllite under cavity contraction.

1.1 The Hardening Soil Model (HSM)

The HSM defines its stress-strain behaviour via hyperbolic equation with stress-dependent stiffness (Schanz et al., 1999). This allows for the simulation of the non-linear stress-strain behaviour shown in the PMT results. Additionally, the model uses equivalent Mohr-Coulomb (MC) strength parameters (cohesion, c' and friction angle, φ'), which can be beneficial for geotechnical assessments that consider MC strength parameters (Choo and Ong, 2015).

The HSM limits the tensile capacity of a model via a user-input tension cut-off value (Plaxis, 2013), which is set to 0 kPa by default for the simulation of soil behaviour. When this feature is disabled (i.e. "Tension cut-off" check box in HSM material properties window is unchecked), the value is fixed at 10^6 kPa. This value acts as a tensile stress threshold which can be developed by the model (Plaxis, 2013). Further explanation on the effect of this feature will be discussed, hereinafter.

2 CONSTRUCTION OF NUMERICAL MODEL

The model geology were simulated to reflect those where PMTs were performed in, spanning 1m in *x-y* directions as presented in Figure 1.

The soil layers were defined using Mohr-Coulomb (MC) model, while the highly fractured phyllite was defined using the HSM. Cavity contraction was simulated through an inwards radial displacement of a cylindrical cavity at the centre of the *x-y* plane. The tension cut-off feature in the HSM was studied to gain insight into its effect on the tensile stress development in the model. A sensitivity study on the equivalent MC strength parameters was conducted to examine their role in governing the development of maximum radial tensile stress, $\sigma_{r,max}$, while keeping the stiffness parameters constant ($E_{50}^{ref} = E_{oed}^{ref} = 109$ MPa, $E_{ur}^{ref} = 326$ MPa (Phangkawira et al., 2016a)). The results of this verification exercise are presented, hereinafter.

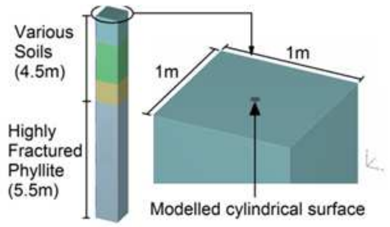

Figure 1 Numerical model geometry of PMT

3 RESULTS AND DISCUSSION

The results from the simulation of cavity contraction are presented in Figure 2 and Table 1.

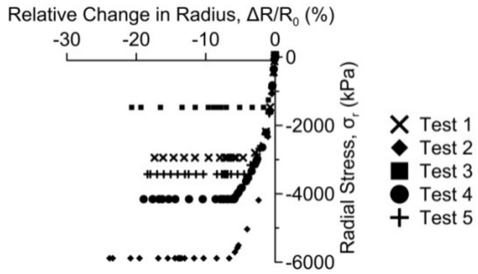

Figure 2 stress-strain results of cavity contraction simulation with different values of c' and φ' (Tension cut-off = 10^6 kPa).

Negative signs in the radial stress, σ_r and the relative change in radius, $\Delta R/R_0$ denotes tensile stress and reduction in cavity radius respectively, indicating cavity contraction. The tension cut-off feature was disabled to allow $\sigma_{r.max}$ to fully develop.

The amount of contraction required for failure increased with the strength of the model. This is shown by the increasing values of $\Delta R/R_0$ at failure with the increase of $\sigma_{r.max}$, indicating that at greater strength, the modelled cavity could contract more before failure.

Table 1 presents the effect of c' and φ' on the development of maximum radial tensile stress, $\sigma_{r.max}$. The relationship among c', φ', and $\sigma_{r.max}$ were governed by Eq. 1, which refers to the horizontal axis intercept of the HSM failure criterion (Plaxis, 2013) shown in Figure 3.

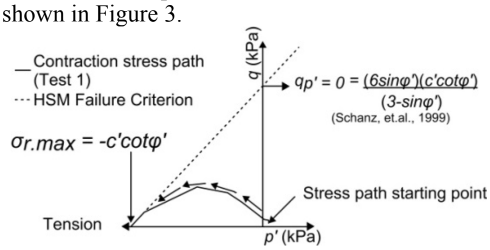

Figure 3 Simulated stress path for the contraction within the model.

$$\sigma_{r.max(calc)} = -c' \cot \varphi' \quad (1)$$

Table 1 Relationship between c', φ', and $\sigma_{r.max}$.

PMT	c' (kPa)	φ' (°)	$\sigma_{r.max}$ (kPa)
1(a)	2400(a)	39(a)	-2942.69
2	4800(b)	39(a)	-5885.38
3	1200(b)	39(a)	-1471.35
4	2400(a)	30(b)	-4156.92
5	2400(a)	35(b)	-3427.56

(a) obtained from the benchmarked model of Phangkawira, et.al. (2016)

(b) other c' and φ' values are generated for sensitivity study only

However, since the magnitude of $\sigma_{r.max}$ can be limited by the tension cut-off feature, it is recommended that the feature is disabled so that the development of $\sigma_{r.max}$ can obey the HSM failure criterion according to Eq. 1. This is done by unchecking the "Tension cut-off" check box in the HSM material properties window.

4 CONCLUSION

This study presents a verification of the necessary technique to model the development of tensile stresses in highly fractured phyllite during cavity contraction. Through this exercise, it was found that the "Tension cut-off" check box in the HSM material properties window must be unchecked in order for the model to be able to carry tensile stress to its full potential, whose capacity is governed by the HSM failure criterion. This modelling technique can be potentially useful for the numerical study of stress development induced by the contraction of a constructed tunnel cavity, since the development of tensile stresses in the modelled rock mass as a result of cavity contraction can now be simulated more accurately and confidently.

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