Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Effect of the uncertainty in soil-water characteristic curve on the estimated shear strength of unsaturated soil

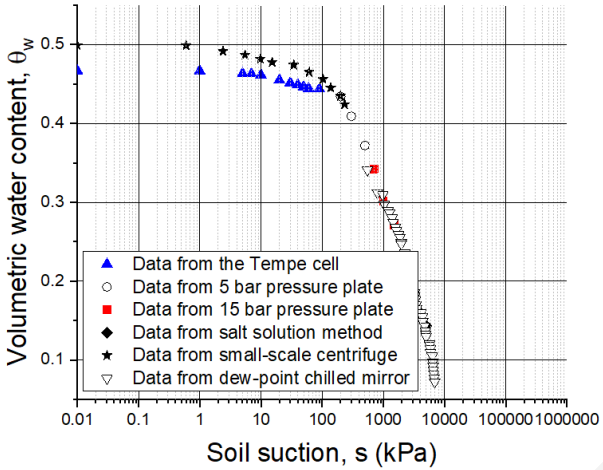
Qian Zhai*, Harianto Rahardjo, Alfrendo Satyanaga,
Guo-liang Dai, Yan-jun Du

Cite this as: Qian Zhai, Harianto Rahardjo, Alfrendo Satyanaga, Guo-liang Dai, Yan-jun Du, 2020. Effect of the uncertainty in soil-water characteristic curve on the estimated shear strength of unsaturated soil. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering-Science A)*, 21(4):317-330. https://doi.org/10.1631/jzus.A1900589

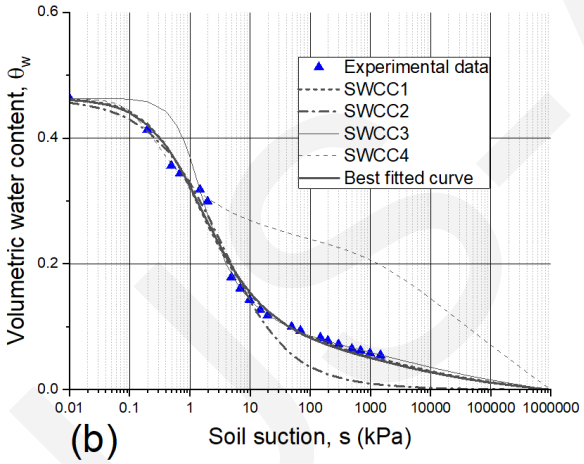
- *Corresponding Author, 101012332@seu.edu.cn
- ORCID: Qian ZHAI, https://orcid.org/0000-0003-4619-2821

Uncertainty of SWCC due to (1) natural variation in soil textures; (2) experimental measurement error; (3) different measurement equipment or techniques; (4) experience of the operator; (5) number of data points collected; (6) range of suction covered; (7) the best fit equation selected; (8) the different forms of SWCC; (9) temperature variation; (10) different initial saturated water contents or different initial void ratios; (11) different confining pressures.

Uncertainty of SWCC

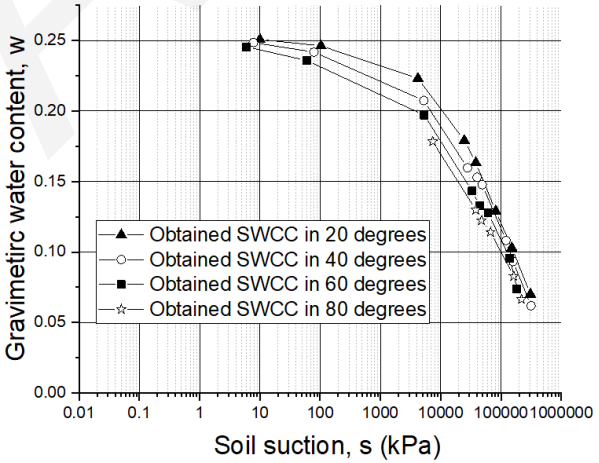


Uncertainty of SWCC due to different measurement techniques (from Rahardjo et al. 2018)



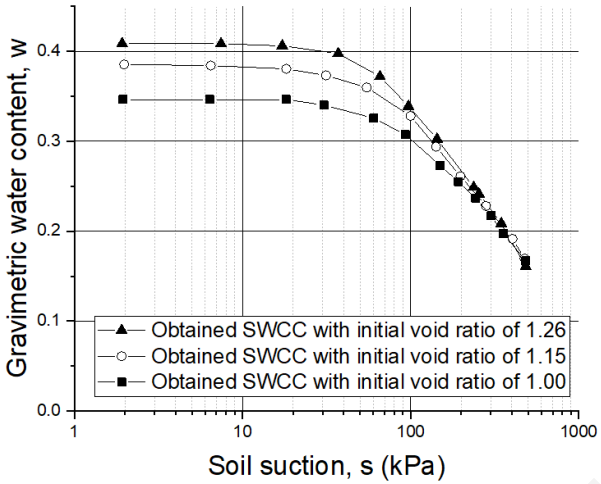
(b)

Uncertainty of SWCC due to different number of data points and suction ranges (modified from Zhai et al. 2013)

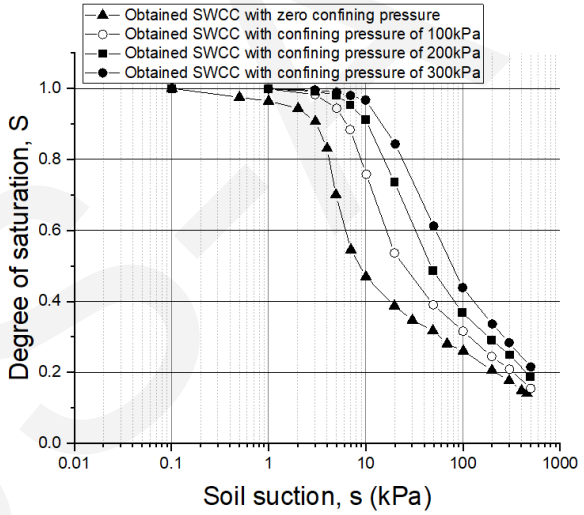


Uncertainty of SWCC due to different temperatures (from Wan et al. 2015)

Uncertainty of SWCC



Uncertainty of SWCC due to different initial void ratios (from Gao et al. 2018)



Uncertainty of SWCC due to different confining pressure (from Gao et al. 2018)

Equations for the shear strength of unsaturated soil

$$\tau_{\mathrm{ff}} = c' + \left(\sigma_{\mathrm{f}} - u_{\mathrm{a}}\right)_{\mathrm{f}} \tan\phi' + \left(u_{\mathrm{a}} - u_{\mathrm{w}}\right)_{\mathrm{f}} \tan\phi^{b},$$

Fredlund et al. (1978)

$$\tau_{\mathrm{ff}} = c' + \left[\begin{array}{l}\left(\sigma_{\mathrm{f}} - u_{\mathrm{a}}\right)_{\mathrm{f}} + \\ \left(\dfrac{\theta - \theta_{\mathrm{r}}}{\theta_{\mathrm{s}} - \theta_{\mathrm{r}}}\right)\left(u_{\mathrm{a}} - u_{\mathrm{w}}\right)_{\mathrm{f}}\end{array}\right] \tan\phi',$$

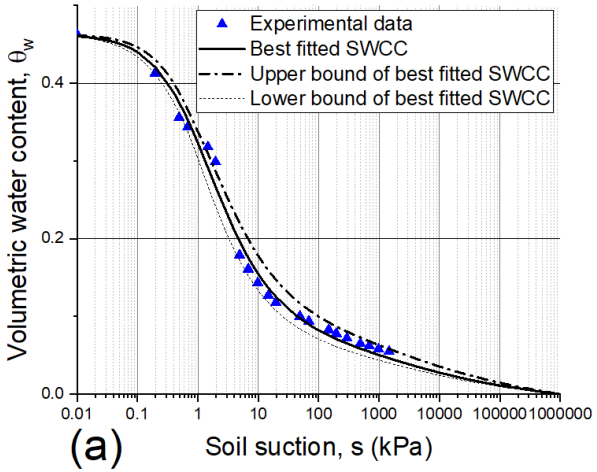
Vanapalli et al. (1996)

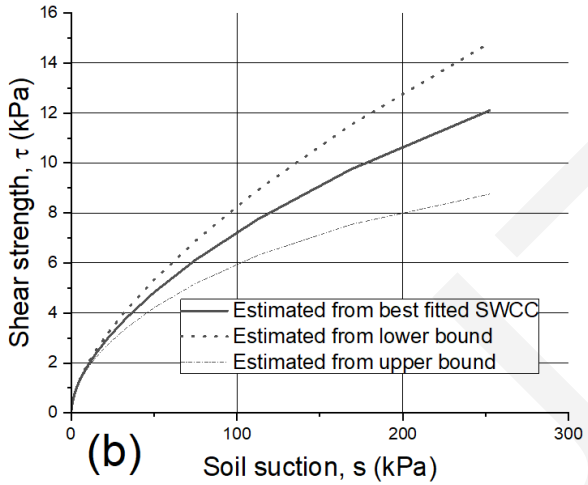
$$\tau = c' + \left(\sigma - u_{\mathrm{a}}\right)\tan\phi' + \frac{S - S'}{1 - S'}\left(u_{\mathrm{a}} - u_{\mathrm{w}}\right)\tan\phi'$$

$$+ \sum_{i=m}^{N} \frac{1}{\pi} \left[\frac{\left(\dfrac{\psi_i}{\psi_{\mathrm{m}}}\right)^2 \alpha_i -}{\sqrt{\left(\dfrac{\psi_i}{\psi_{\mathrm{m}}}\right)^2 - 1}}\right] \left(u_{\mathrm{a}} - u_{\mathrm{w}}\right)\left[S(\psi_i + 1) - S(\psi_i)\right],$$

Zhai et al. (2019)

Effect of variability of SWCC on estimated shear strength

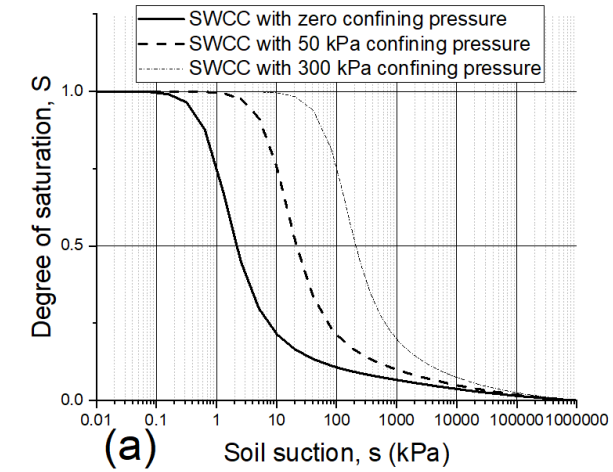


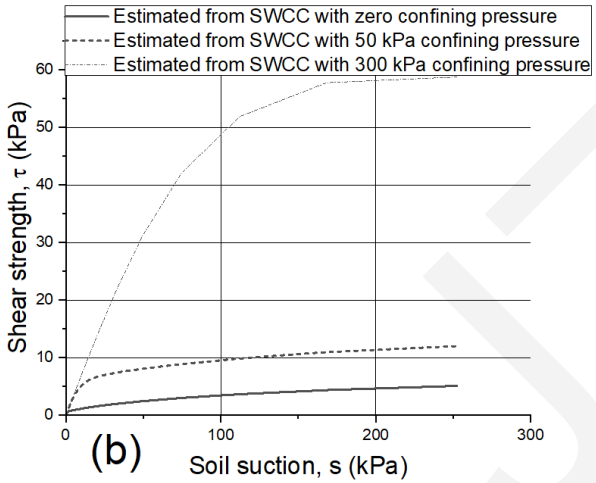


Category 1: The uncertainty of SWCC in the best fitting procedure (e.g., measurement errors, incapacity of best fit equation, number of data points and suction ranges) can be quantified by using the upper and lower bounds of determined SWCC (Zhai and Rahardjo, 2013)

The upper & lower bounds of determined SWCC can be incorporated in the equations (e.g., Fredlund et al, 1978, Vanapalli et al., 1996, Zhai et al., 2019) for the estimation of the shear strength of the unsaturated soil.

Effect of variability of SWCC on estimated shear strength

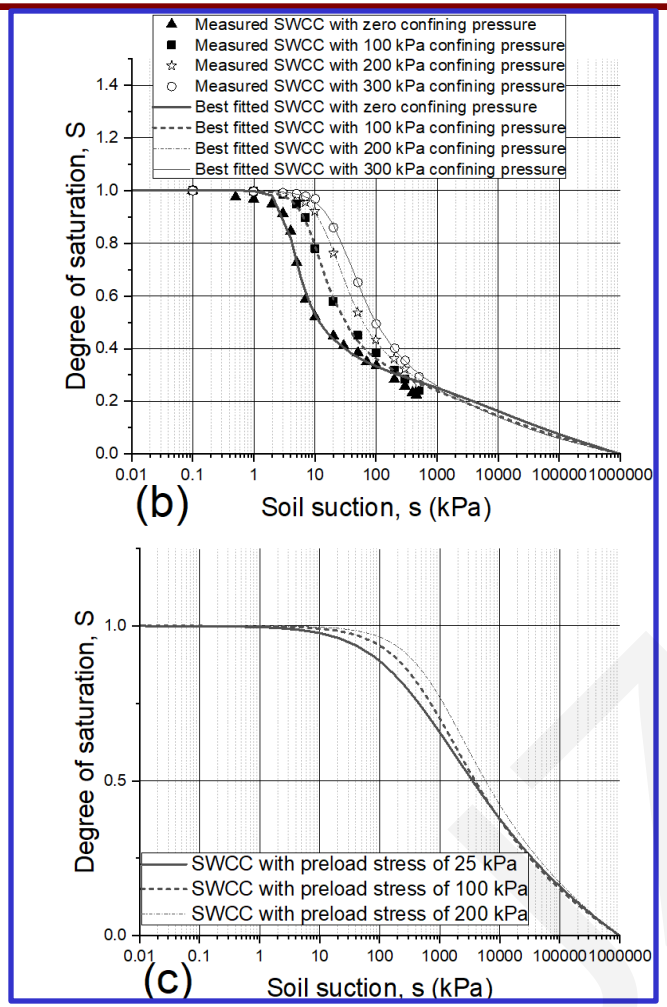




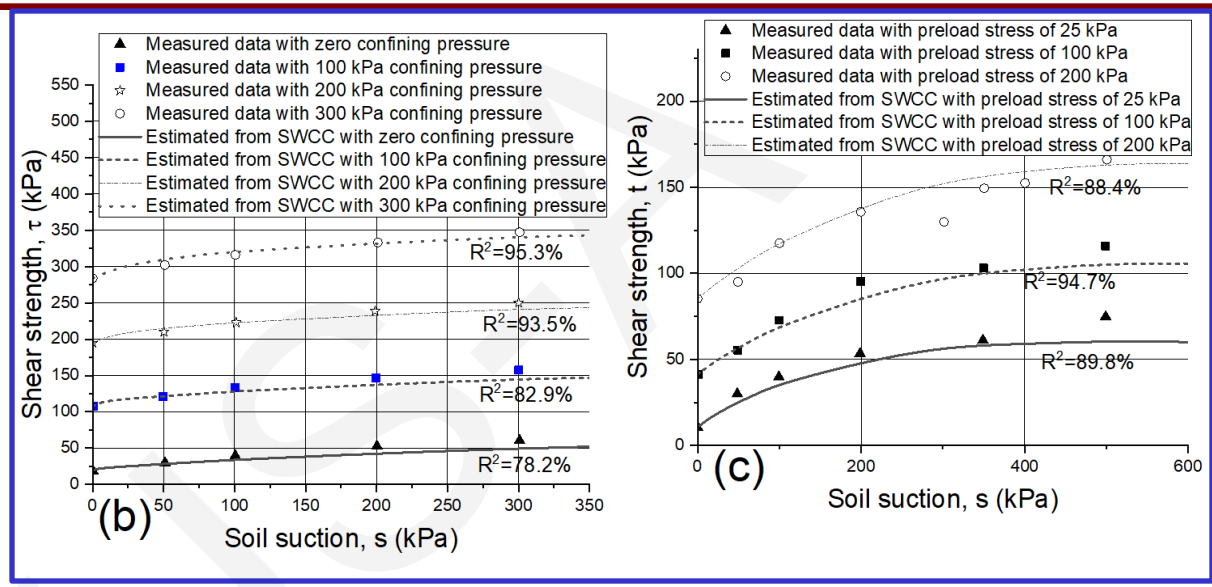
Category 2: The effects of temperature, initial water content/ void ratio, confining pressures on the SWCC can be simulated by a series of SWCCs. Different SWCCs are corresponding to different state conditions of the soil.

Correct SWCC corresponding to given state condition should be incorporated in the equations (e.g., Fredlund et al, 1978, Vanapalli et al., 1996, Zhai et al., 2019) for the estimation of the shear strength of the unsaturated soil.

Comparison between the estimated results and measured data

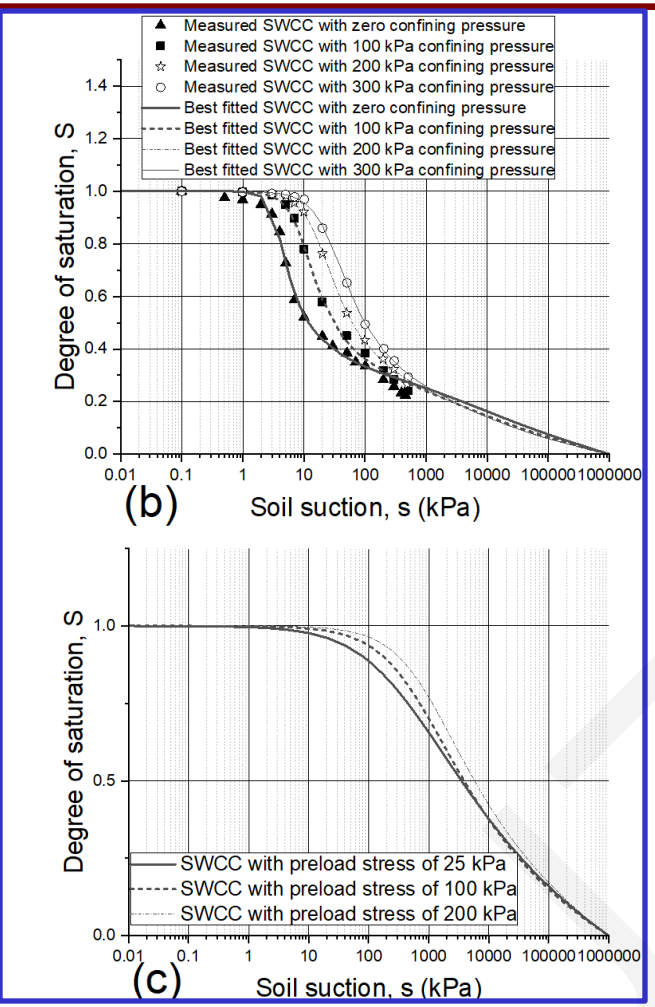


Measured different SWCCs for the soil with different state conditions

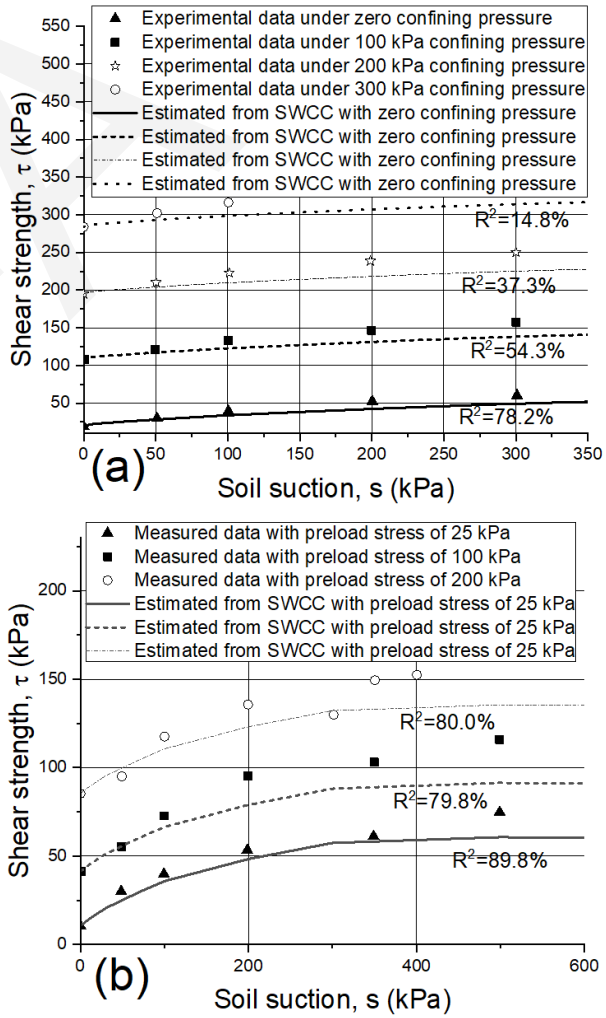


Estimated shear strengths of unsaturated soils by using different SWCCs incorporating state conditions

Comparison between the estimated results and measured data



If the effect of state condition on the SWCC is ignored, then only one SWCC is obtained (e.g., Tempe cell, pressure plate, WP4, centrifuge). It is observed that the estimated shear strengths of unsaturated soils from single SWCC are less accurate.



Measured different SWCCs for the soil with different state conditions

Conclusions

1, The uncertainty of SWCC due to different factors are reviewed. The uncertainty of SWCC cannot be avoided in the practical engineering and it should be incorporated in the estimation of the shear strength of unsaturated soil.

2, The uncertainty of SWCC in the best fitting procedure can be quantified using the method from Zhai and Rahardjo (2013) and can be incorporated in the equations for the estimation of shear strength of unsaturated soil.

3, The uncertainty of SWCC due to different state conditions can be simulated by a series of SWCCs. Different SWCCs corresponding to different state conditions should be adopted in the estimation of shear strength of unsaturated soil.