Unsaturated soil model effects on the propagation of the saturated zone in levees during flooding

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1 Introduction

Design of waterside slopes for rapid drawdown typically assumes an initial state of steady seepage prior to drawdown. However, levees built from low permeability soils are unlikely to reach this state during a flood, and a method has been developed to evaluate the degree of seepage propagation based on a linear approximation of the phreatic surface at end of flooding as shown in Fig 1. For this reason, it is prudent to consider the analysis of levee soils using unsaturated soil mechanics.

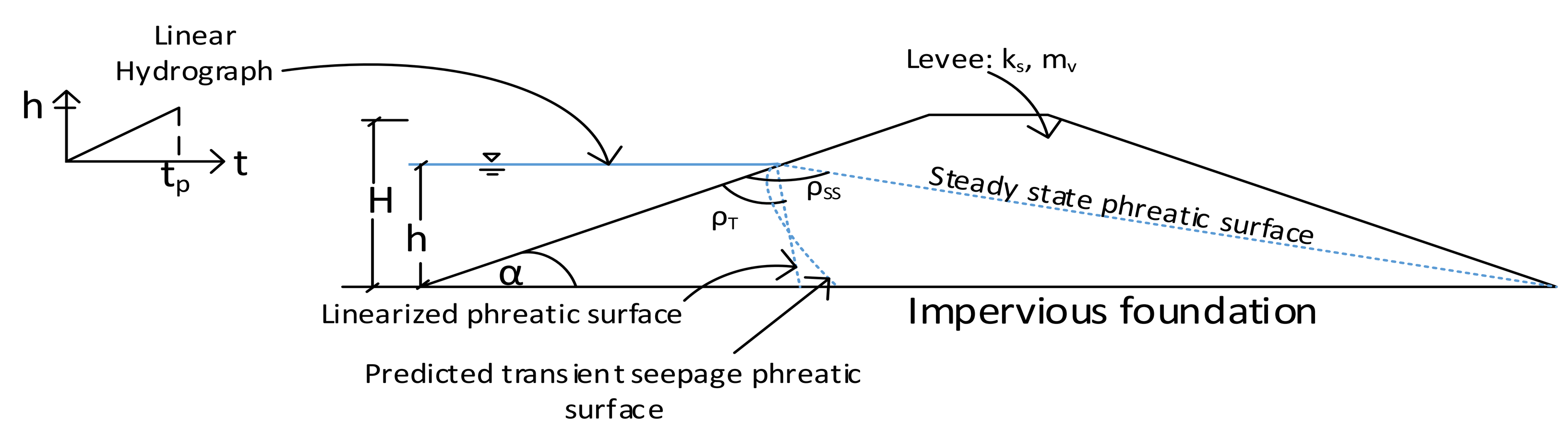

Fig 1. Idealized levee saturation after flood

In the face of limited, or often times, no site specific soil water characteristic curve (SWCC) and hydraulic conductivity function (HCF) test data, geotechnical engineers are compelled to select unsaturated soil properties for use based on other soil data; therefore, it is important for practicing engineers to be aware of how model selection may influence seepage propagation in various engineering applications.

2 Objectives

This study parametrically compares results obtained using the Slide v. 8.0 Simple model to the Fredlund and Xing, and van Genuchten models for SWCC and HCF for levees with different flood, geometric and soil properties. The Simple model approximates the SWCC and HCF curves with straight lines instead of the curved relationships used by many other models.

3 Methodology

Figure 2 summarizes the methodology used for the study.

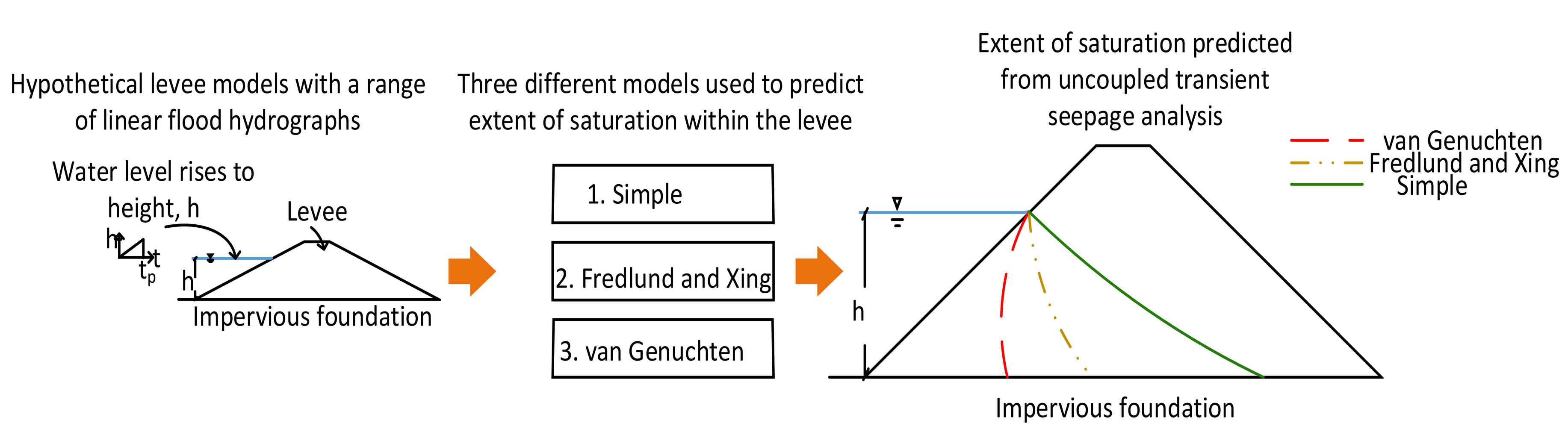

Fig 2. Methods used to predict extent of levee saturation using van Genuchten, Fredlund and Xing, and a Simple unsaturated soil model

Tables 1 and 2 summarize model parameters for three soil types used in the study.

Table 1. θ_s, θ_r, k_s and van Genuchten (1980) parameters for three soil types

Soil type	θ_s	θ_r	k_s (m/s) Measured	k_s (m/s) Adjusted	α (1/cm)	n
Soil 1	0.469	0.190	3.5×10^{-4}	3×10^{-4}	0.0050	7.09
Soil 2	0.396	0.131	5.7×10^{-7}	3×10^{-6}	0.00423	2.06
Soil 3	0.446	0	9.5×10^{-9}	3×10^{-8}	0.00152	1.17

Note: Based on properties of Touchet silt loam, silt loam G.E.3, and Beit Netofa clay from van Genuchten (1980) with adjusted values of k_s

Methodology contd.

Table 2. Fredlund and Xing (1994) parameters for three soil types

Soil type	*a* (kPa)	*b*	*c*	*A* (kPa)	*B*	*C*
Soil 1[i]	15	7.05	0.506	8.55	13.07	1.96
Soil 2[ii]	10.5	4.5	0.4	90	1.5	160
Soil 3[iii]	389	0.685	1.176	6746	0.549	201.1

[i] Based on Leong and Rahardjo (1997) data for Touchet silt loam with a adjusted from 7.64 kPa to 15 kPa.
[ii] Parameters assumed to approximate behavior of Silt loam G.E.3 (van Genuchten 1980).
[iii] Based on Leong and Rahardjo (1997) data for Beit Netofa clay.

Saturated hydraulic conductivity, k_s, saturated (θ_s) and residual (θ_r) water contents used for the different soil types are the same for all three models.

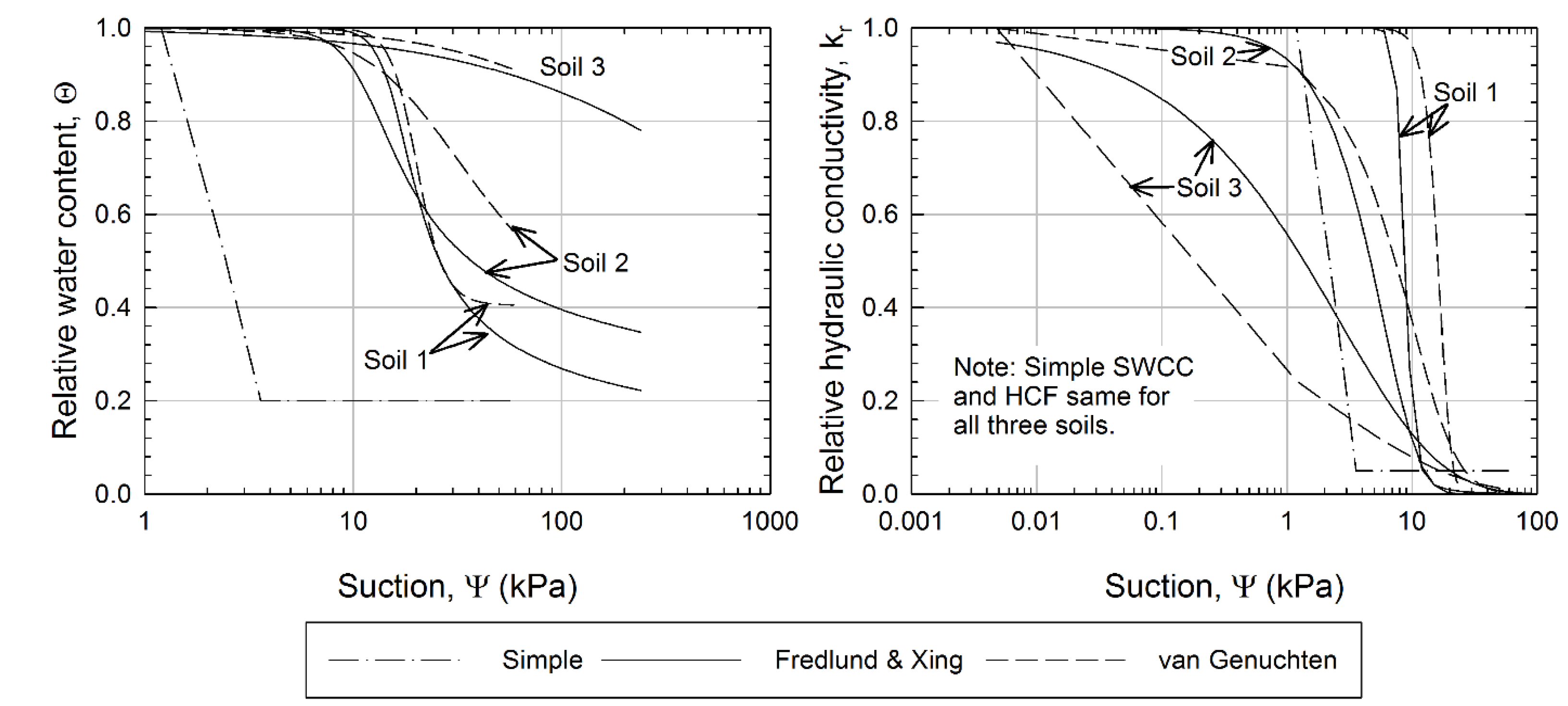

Fig 3. Comparison of Simple, Fredlund and Xing, and van Genuchten models SWCC and HCF models

4 Results and Discussion

The degree of seepage progression within the levee depends on a time factor, T_{sat}, which is function of levee geometry (α), levee soil saturated hydraulic conductivity (k_s), levee soil volume compressibility(m_v), unit weight of water (γ_w),flood time to peak (t_p), and flood height (h).
The extent of saturation achieved during transient seepage with respect to steady state conditions is described by the ratio between the two angles, $U_{sat} = \rho_T / \rho_{SS}$, shown in Fig 1. Figure 4 shows plots of U_{sat} versus T_{sat}, and Figure 5 shows hyperbolic curves representation of the three models.

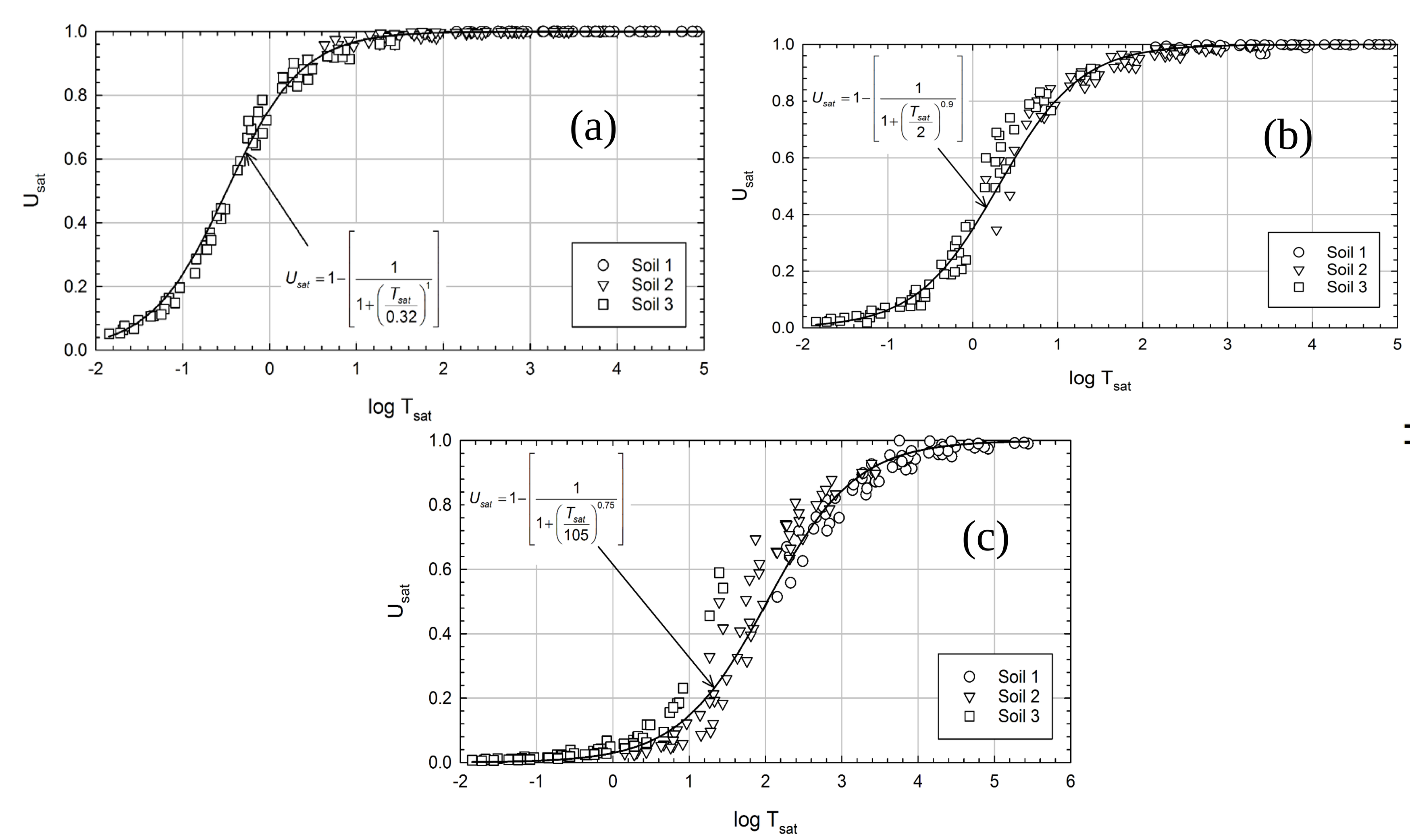

Fig 4. Extent of levee saturation predicted by a) Simple, b)Fredlund and Xing, and c) van Genuchten models

$$T_{sat} = \tan\alpha\left(\frac{k_s}{m_v\gamma_w}\right)\left(\frac{t_p}{h^2}\right)$$

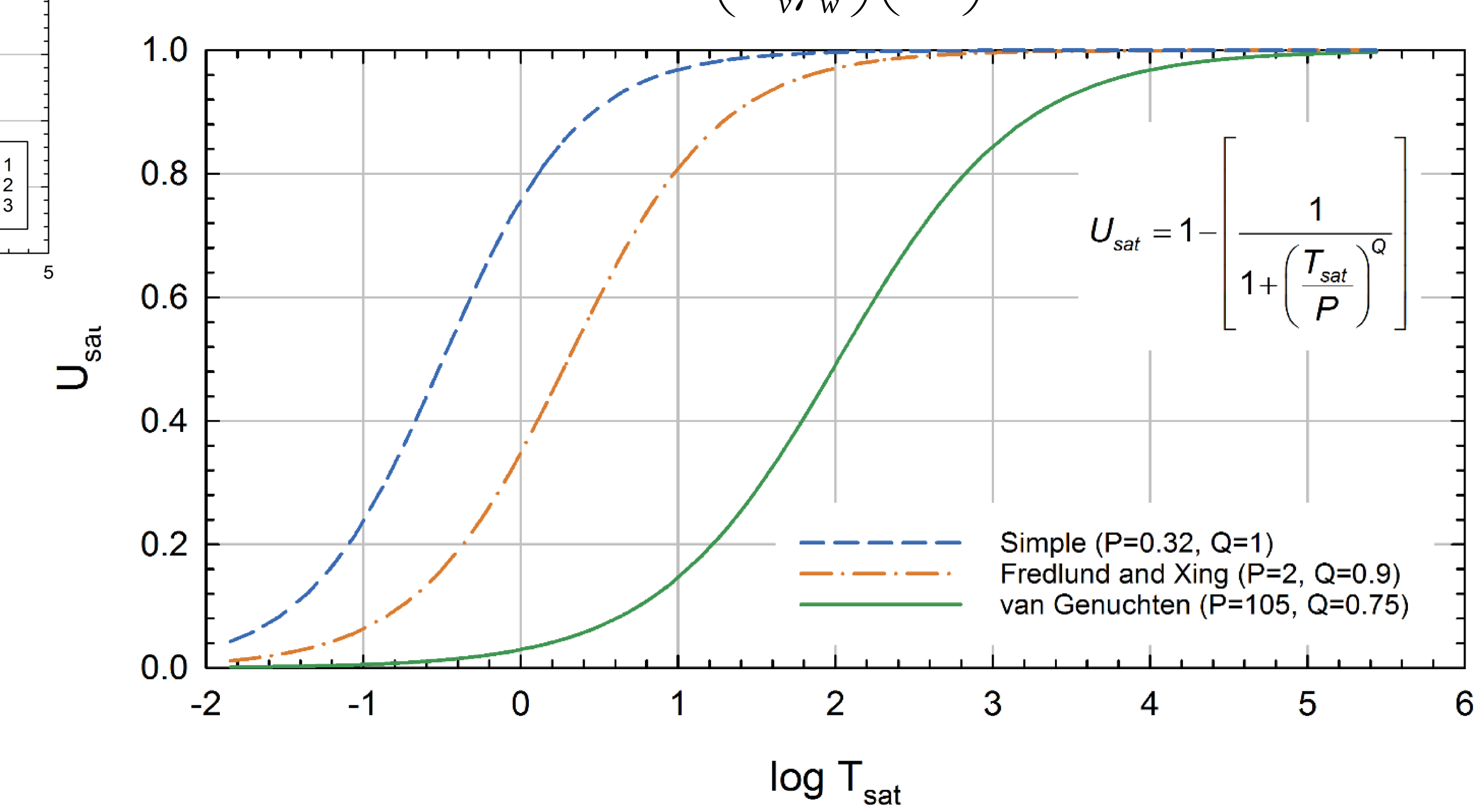

Fig 5. Comparison of hyperbolic curves for estimation of levee saturation

5 Conclusions

The van Genuchten and Fredlund and Xing models predict lower extent of saturation compared to the Simple model. The higher degree of scatter observed in results for the van Genuchten model suggests that the predicted behavior is most sensitive to the model parameters for the van Genuchten model, and hence caution should be used to select values for α and n consistent with the hydraulic conductivity. For more realistic assessment of levee seepage, van Genuchten is recommended. However for cases where unsaturated soil properties are unknown or very uncertain, the Simple model may be appropriate for predicting the start-of-drawdown phreatic surface for use with multistage RDD analysis.

6 References

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Van Genuchten, M. T. (1980). "A closed-form equation for predicting the hydraulic conductivity of unsaturated soils 1," Soil Science Society of America Journal, 44(5),892-898.
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