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Limit Analysis of Reinforced Embankments on Soft Soil: Electronic Annex 1

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Abstract

This document forms the electronic annex to the paper 'Limit Analysis of Reinforced Embankments on Soft Soil'. It contains graphs that document a comprehensive parametric study into the stability of a reinforced embankment.

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1. Nomenclature

Symbol	Definition
c'	cohesion of the soil of embankment fill
ϕ'	friction angle of soil of embankment fill
γ	unit weight of soil of embankment fill
c_u	shear strength of soft soil
R	rupture strength of reinforcement per unit width
H	height of embankment
D	thickness of soft soil
q	surcharge
n	side slope gradient $(nH : 1V)$
α	interface coefficient between reinforcement and soft soil/embankment fill

2. Design charts plotting ϕ' vs $c_u/\gamma H$ for low rupture strength $R/\gamma H^2 = 0.1$

2.1. *Without surcharge $q/\gamma H$=0*

The following charts present the relationship between angle of shearing resistance ϕ' in the embankment fill required to prevent failure as a function of the normalised undrained shear strength of the soft soil $c_u/\gamma H$ for various values of $c'/\gamma H$, H/D, n. These charts relate to a reinforcement strength $R/\gamma H^2 = 0.1$ and a zero surcharge condition. Collapse is independent of the values of interface friction coefficient α studied (0.6, 0.8, 1.0).

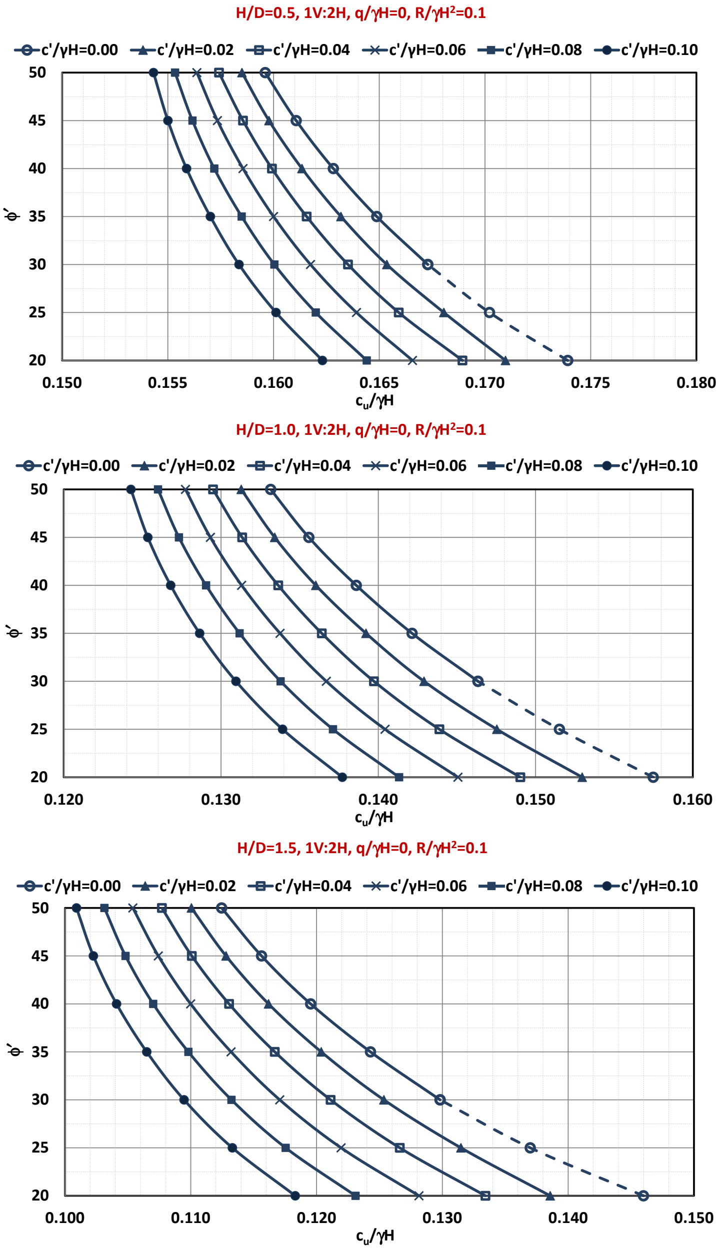

Figure 1: Required soil properties for embankment without surcharge and low rupture strength reinforcement, n=2 (Note: Dash line part of the graph is unstable with $c' = 0$).

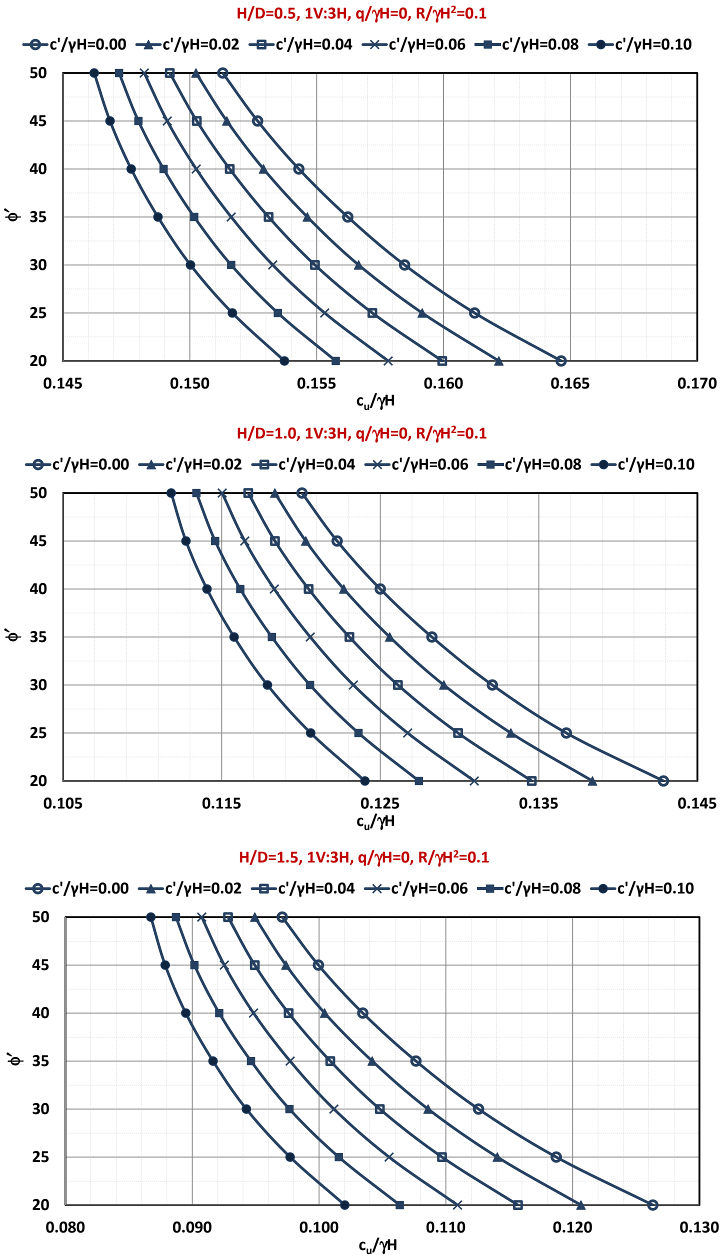

Figure 2: Required soil properties for embankment without surcharge and low rupture strength reinforcement, n=3.

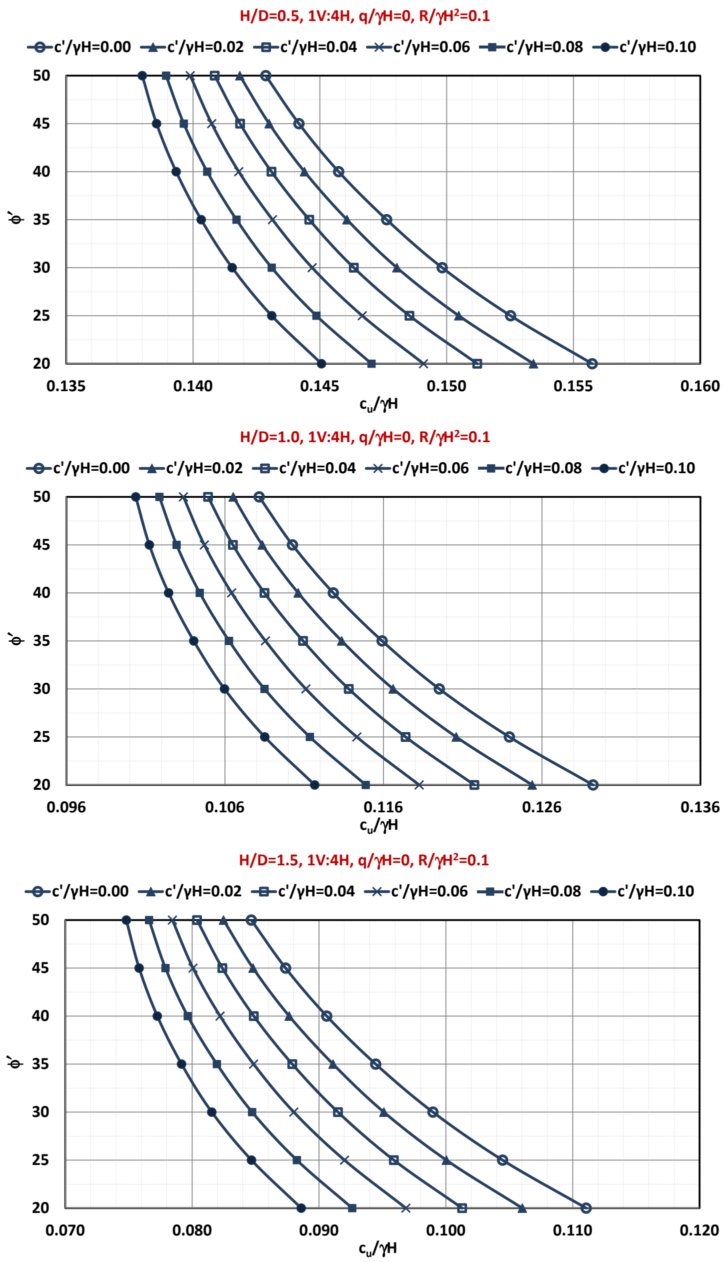

Figure 3: Required soil properties for embankment without surcharge and low rupture strength reinforcement, n=4.

2.2. With surcharge $q/\gamma H$=0.1

The following charts present the relationship between angle of shearing resistance ϕ' in the embankment fill required to prevent failure as a function of the normalised undrained shear strength of the soft soil $c_u/\gamma H$ for various values of $c'/\gamma H$, H/D, n. These charts relate to a reinforcement strength $R/\gamma H^2 = 0.1$ and a surcharge condition $q/\gamma H$=0.1. Collapse is independent of the values of interface friction coefficient α studied (0.6, 0.8, 1.0).

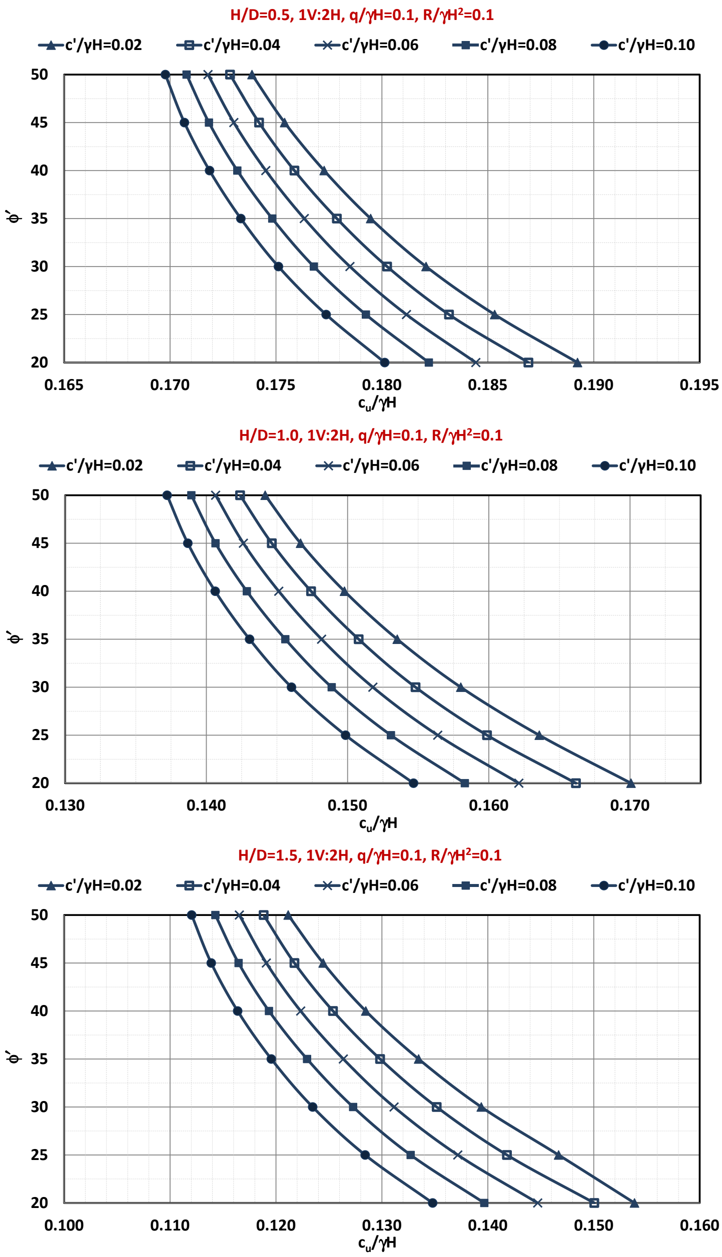

Figure 4: Required soil properties for embankment with surcharge and low rupture strength reinforcement, n=2.

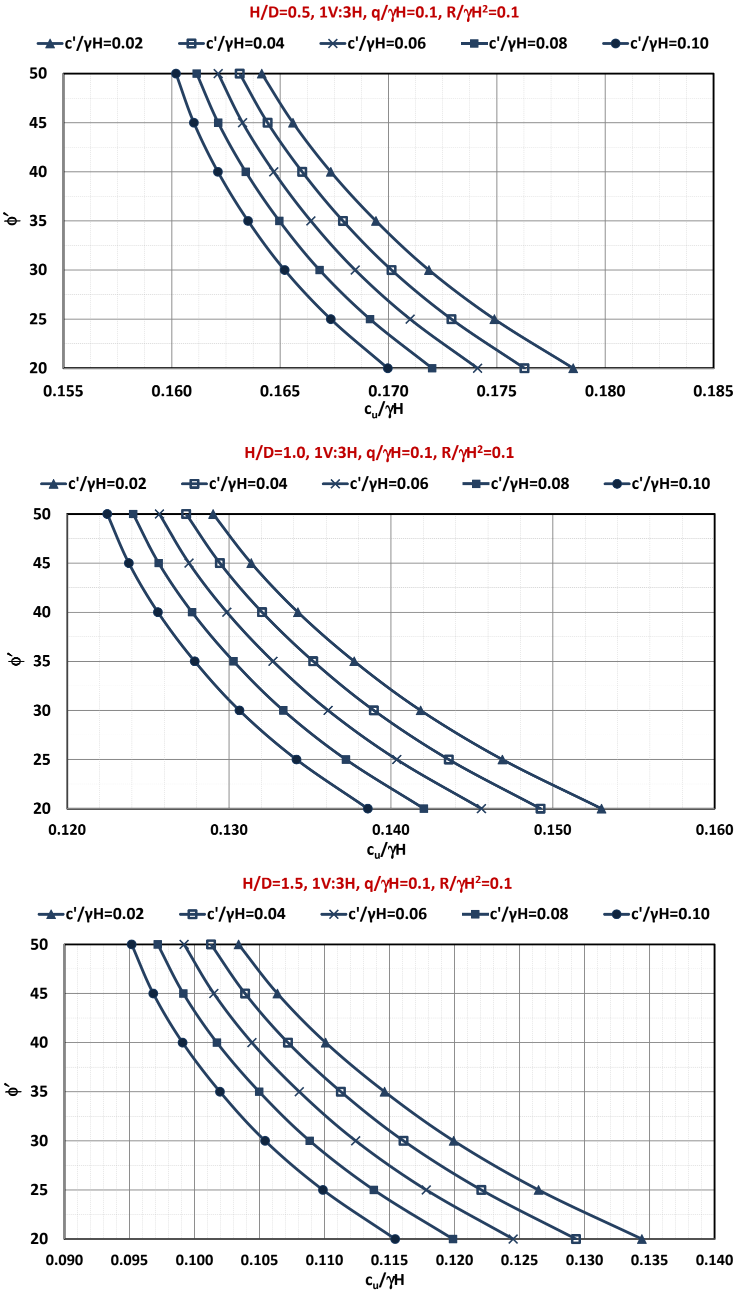

Figure 5: Required soil properties for embankment with surcharge and low rupture strength reinforcement, n=3.

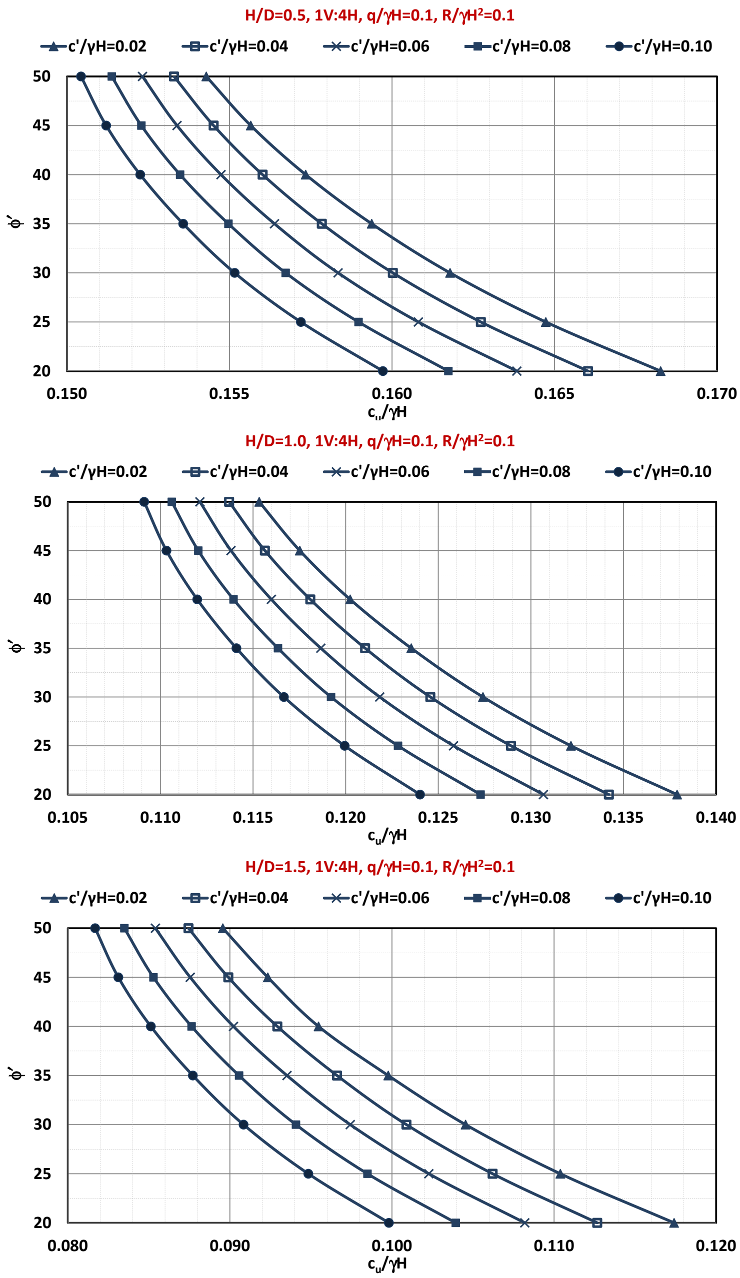

Figure 6: Required soil properties for embankment with surcharge and low rupture strength reinforcement, n=4.

3. Design charts plotting ϕ' vs $c_u/\gamma H$ for high rupture strength $R/\gamma H^2 = 1.0$

3.1. Without surcharge $q/\gamma H$=0

The following charts present the relationship between angle of shearing resistance ϕ' in the embankment fill required to prevent failure as a function of the normalised undrained shear strength of the soft soil $c_u/\gamma H$ for various values of $c'/\gamma H$, H/D, n and α. These charts relate to a reinforcement strength $R/\gamma H^2 = 1.0$ and to a zero surcharge condition.

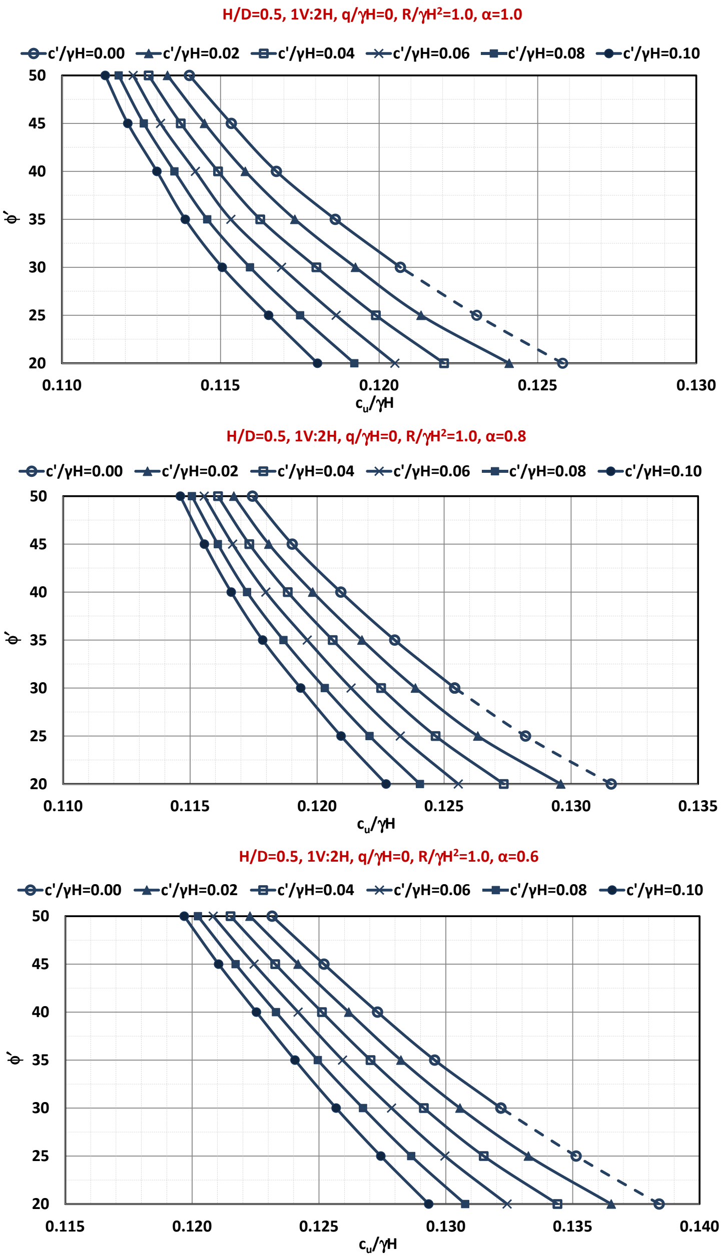

Figure 7: Required soil properties for embankment without surcharge and high rupture strength reinforcement, n=2, H/D=0.5 (Note: Dash line part of the graph is unstable with $c' = 0$).

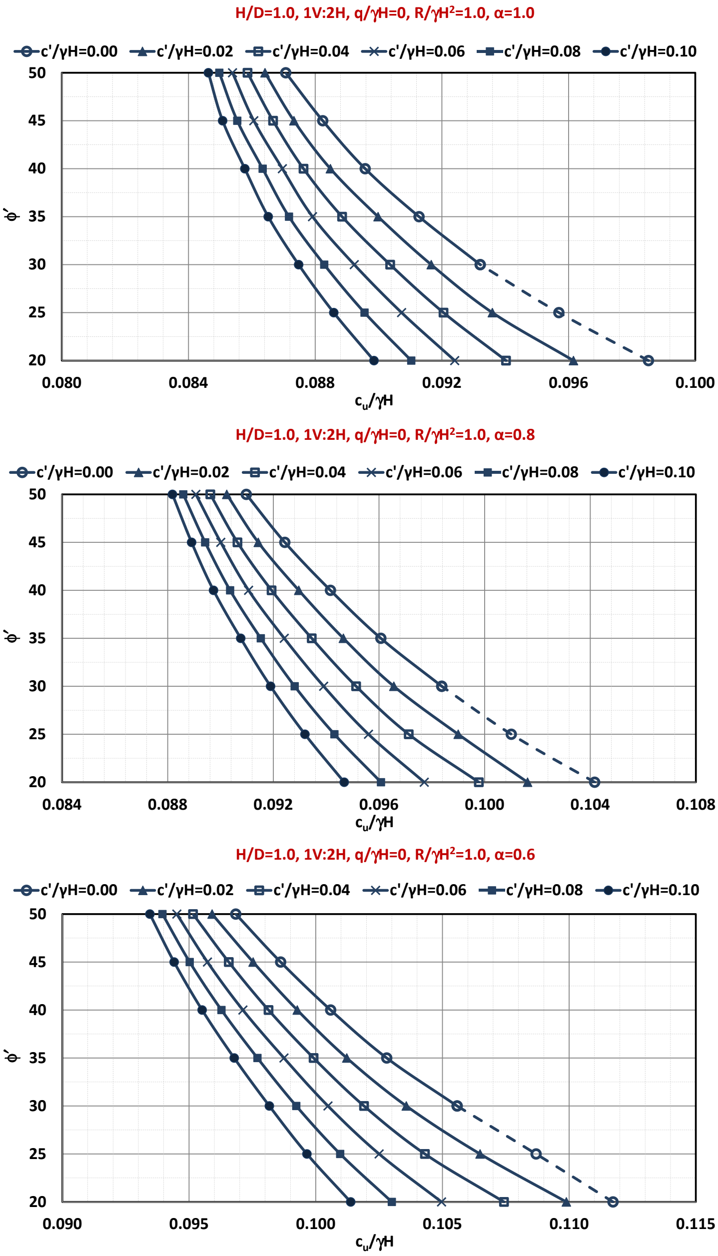

Figure 8: Required soil properties for embankment without surcharge and high rupture strength reinforcement, n =2, H/D=1.0 (Note: Dash line part of the graph is unstable with $c' = 0$).

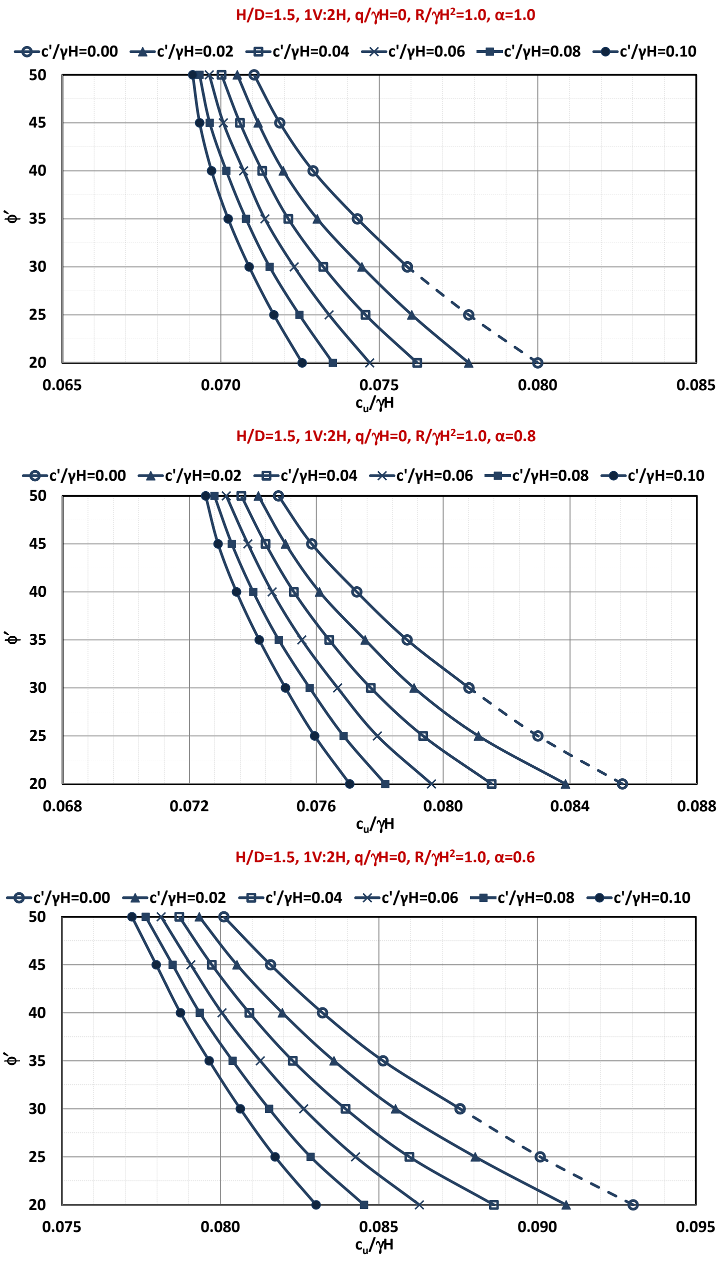

Figure 9: Required soil properties for embankment without surcharge and high rupture strength reinforcement, n=2, H/D=1.5 (Note: Dash line part of the graph is unstable with $c' = 0$).

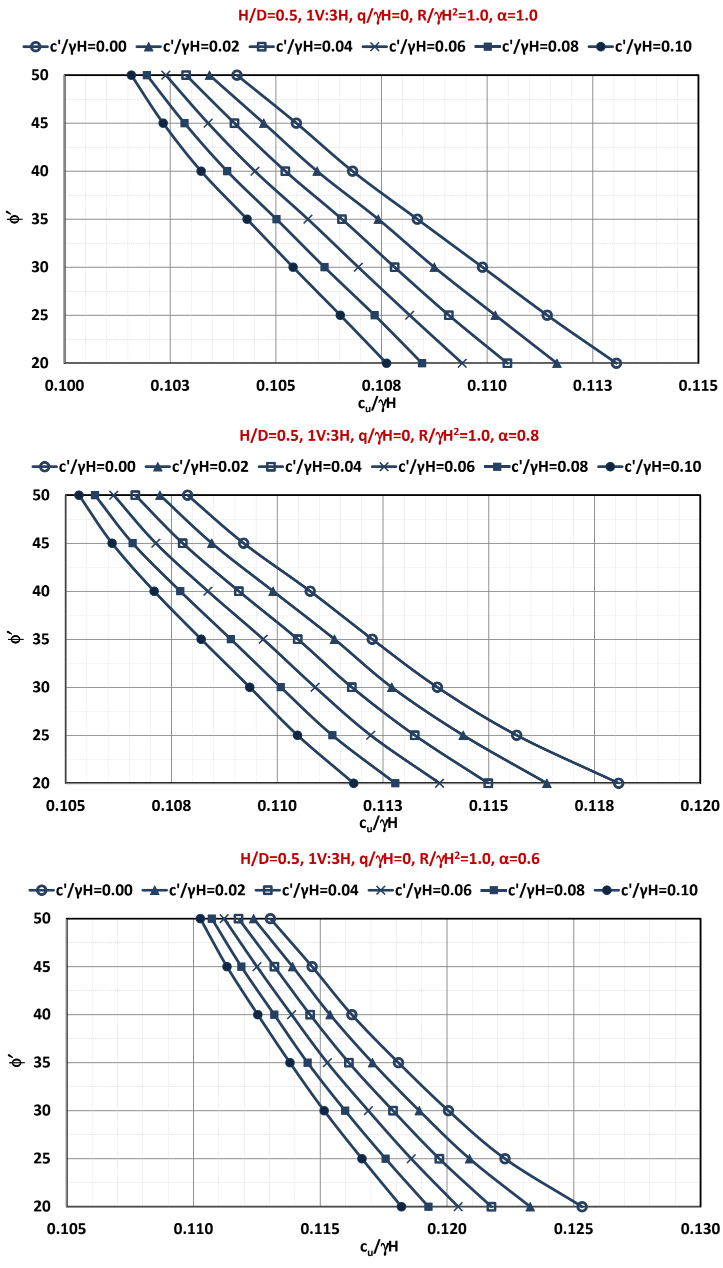

Figure 10: Required soil properties for embankment without surcharge and high rupture strength reinforcement, n=3, H/D=0.5.

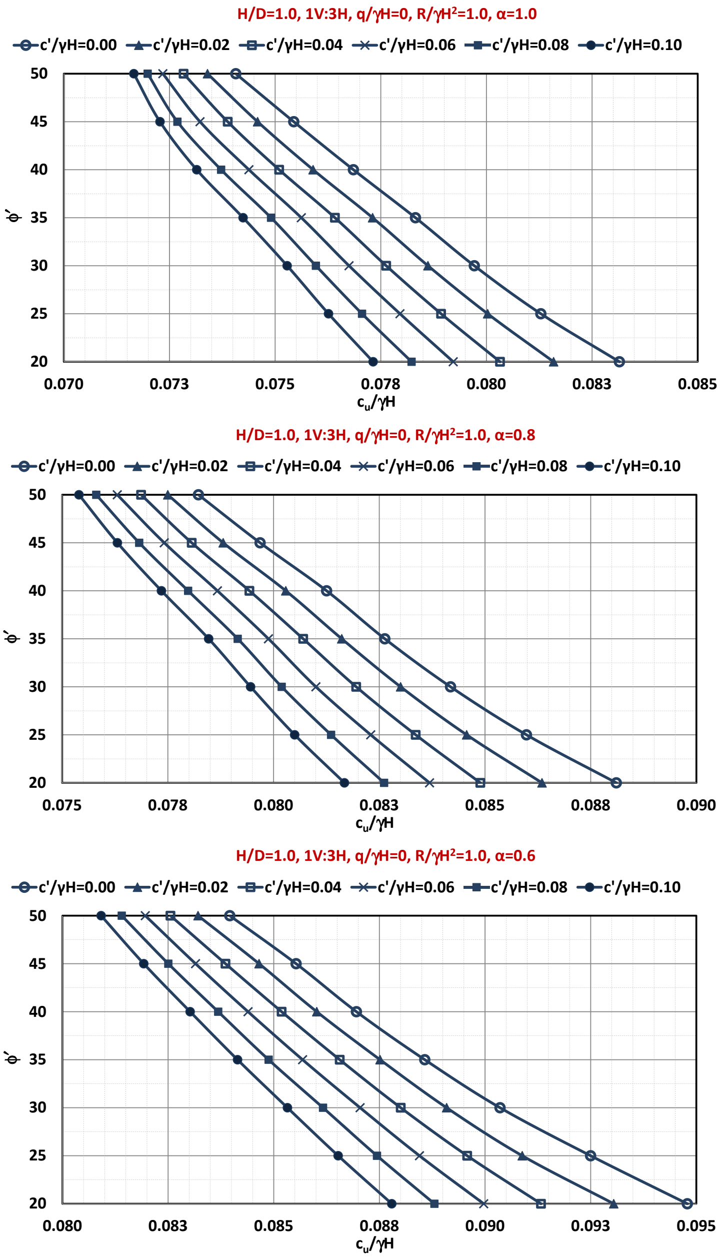

Figure 11: Required soil properties for embankment without surcharge and high rupture strength reinforcement n=3, H/D=1.0.

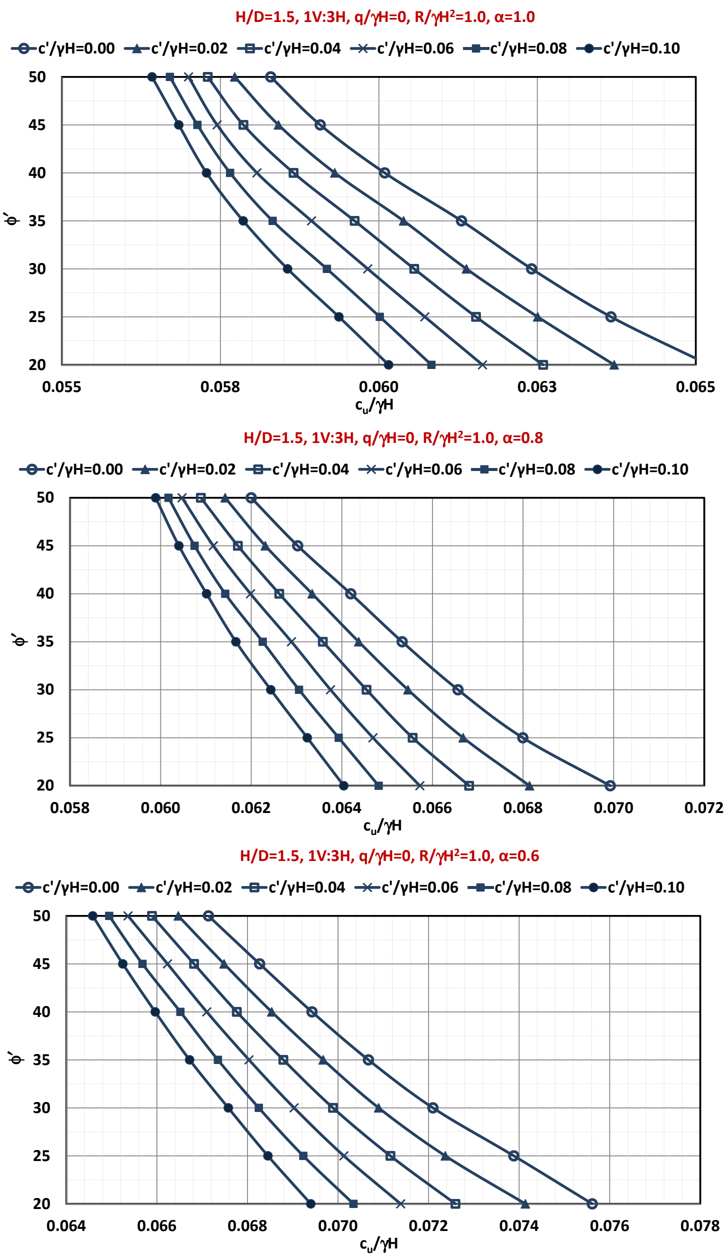

Figure 12: Required soil properties for embankment without surcharge and high rupture strength reinforcement n=3, H/D=1.5.

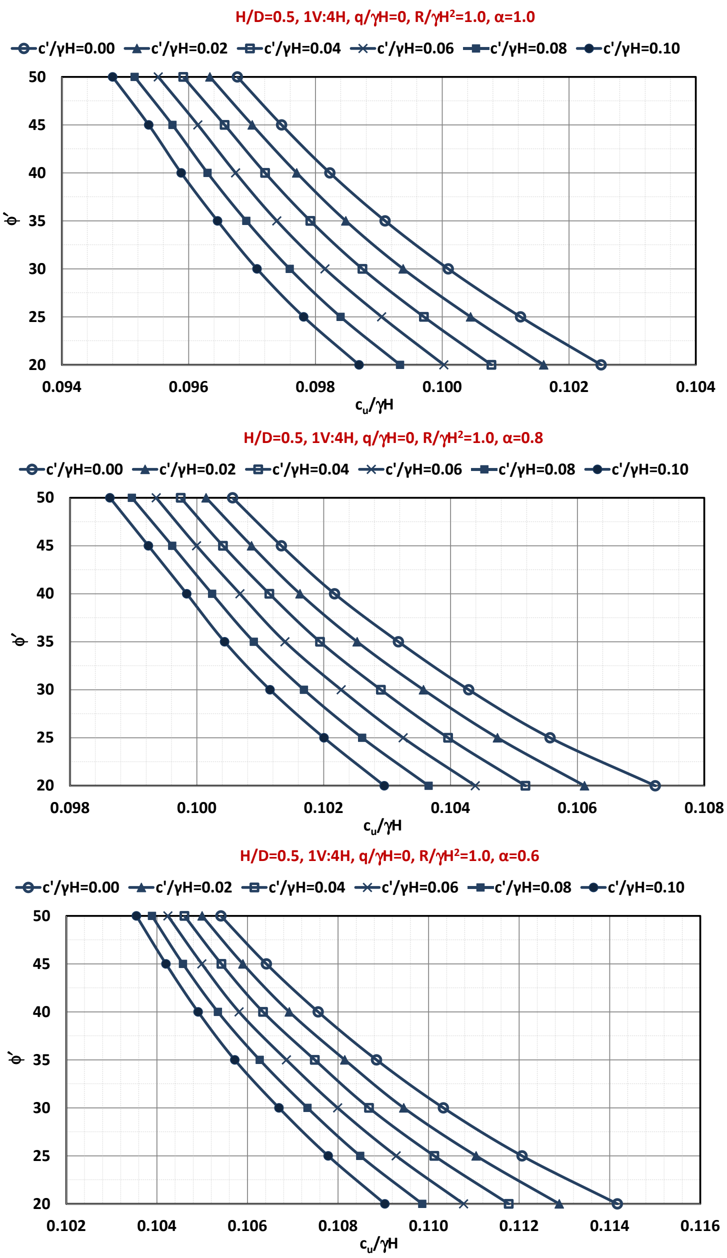

Figure 13: Required soil properties for embankment without surcharge and high rupture strength reinforcement n=4, H/D=0.5.

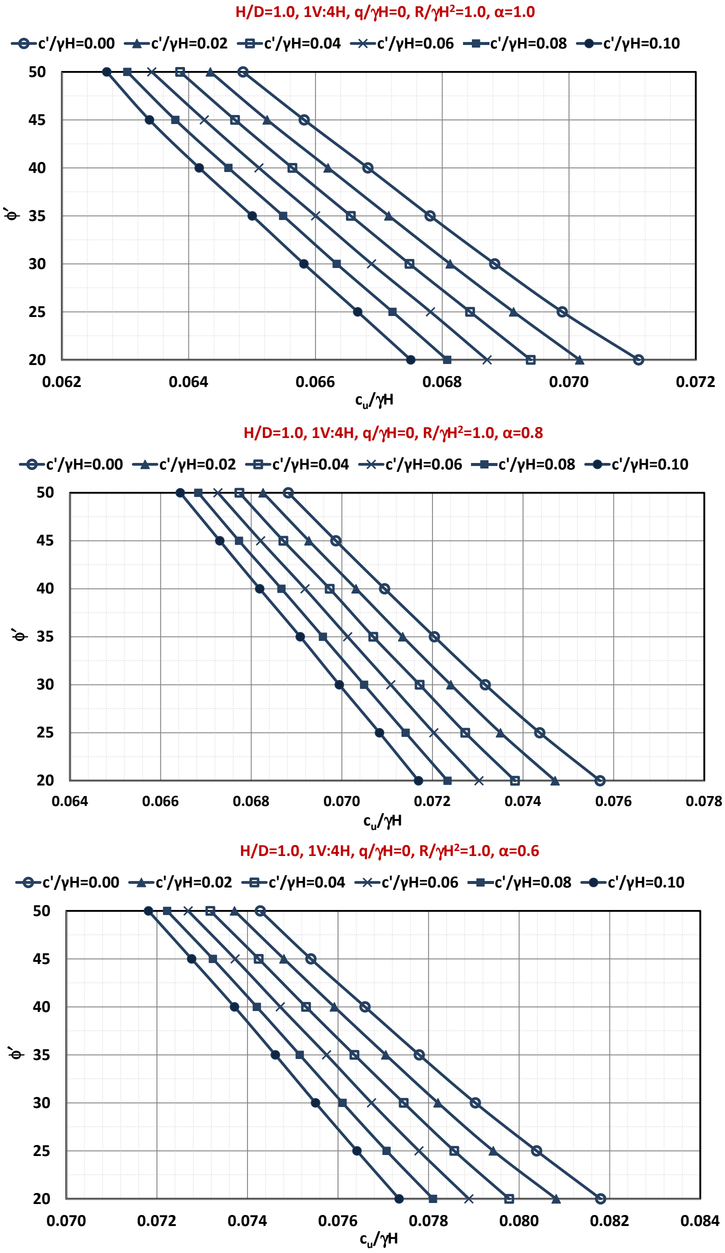

Figure 14: Required soil properties for embankment without surcharge and high rupture strength reinforcement n=4, H/D=1.0.

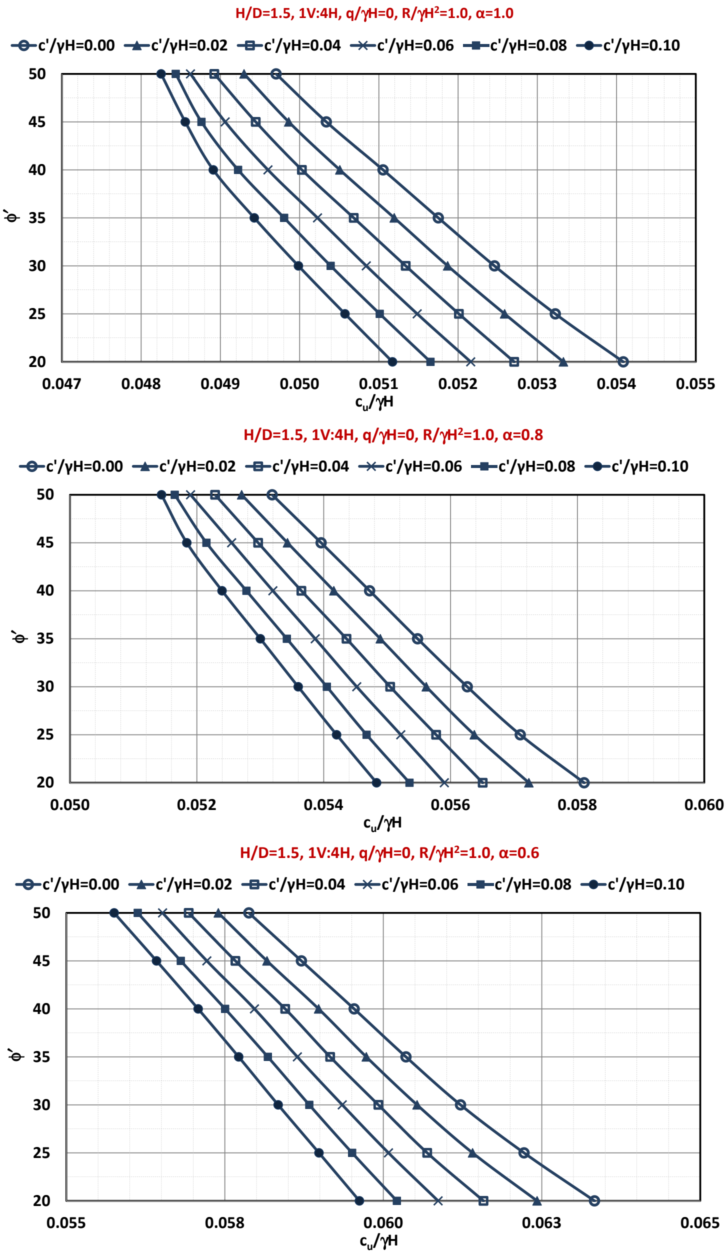

Figure 15: Required soil properties for embankment without surcharge and high rupture strength reinforcement n=4, H/D=1.5.

3.2. With surcharge $q/\gamma H$=0.1

The following charts present the relationship between angle of shearing resistance ϕ' in the embankment fill required to prevent failure as a function of the normalised undrained shear strength of the soft soil $c_u/\gamma H$ for various values of $c'/\gamma H$, H/D, n and α. These charts relate to a reinforcement strength $R/\gamma H^2 = 1.0$ and a surcharge condition $q/\gamma H$=0.1.

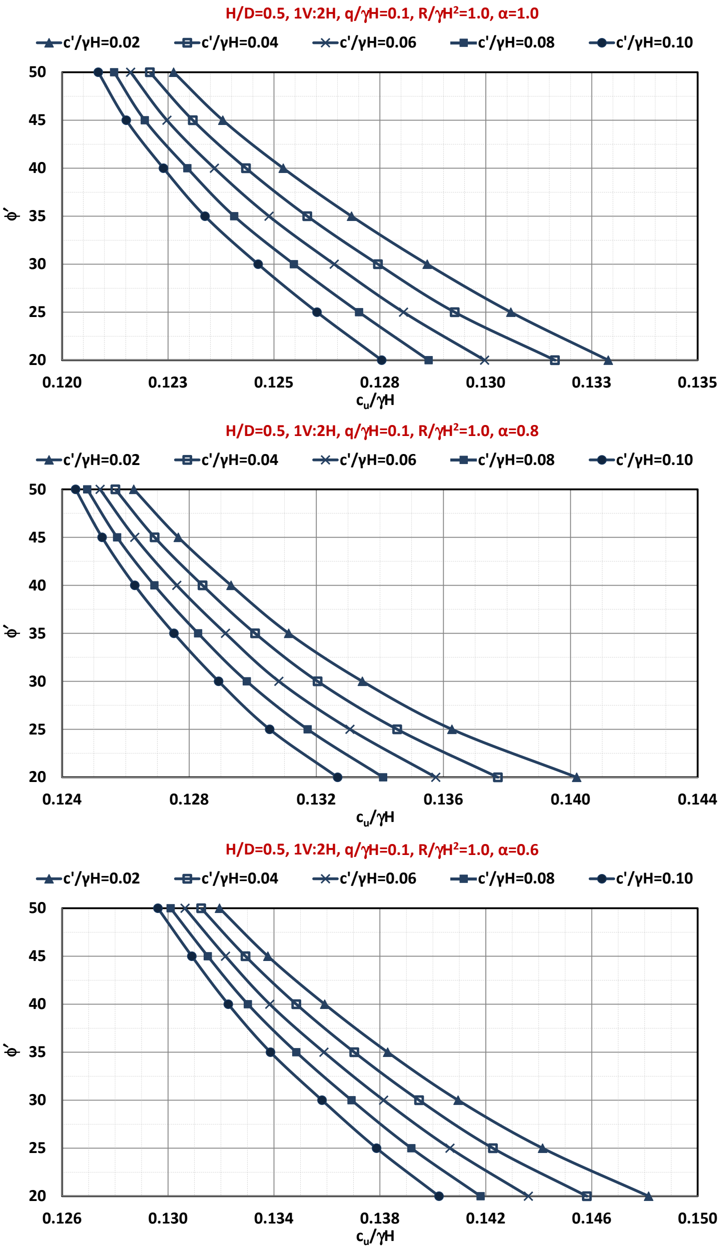

Figure 16: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=2, H/D=0.5.

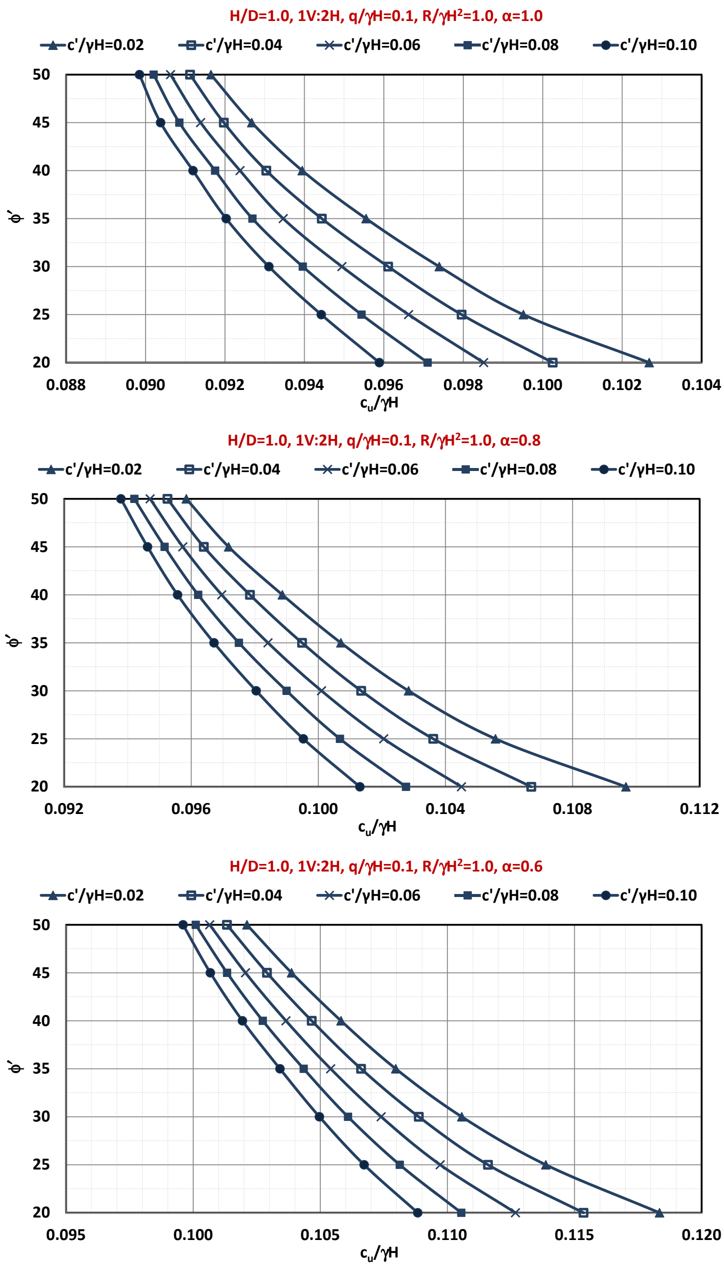

Figure 17: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=2, H/D=1.0.

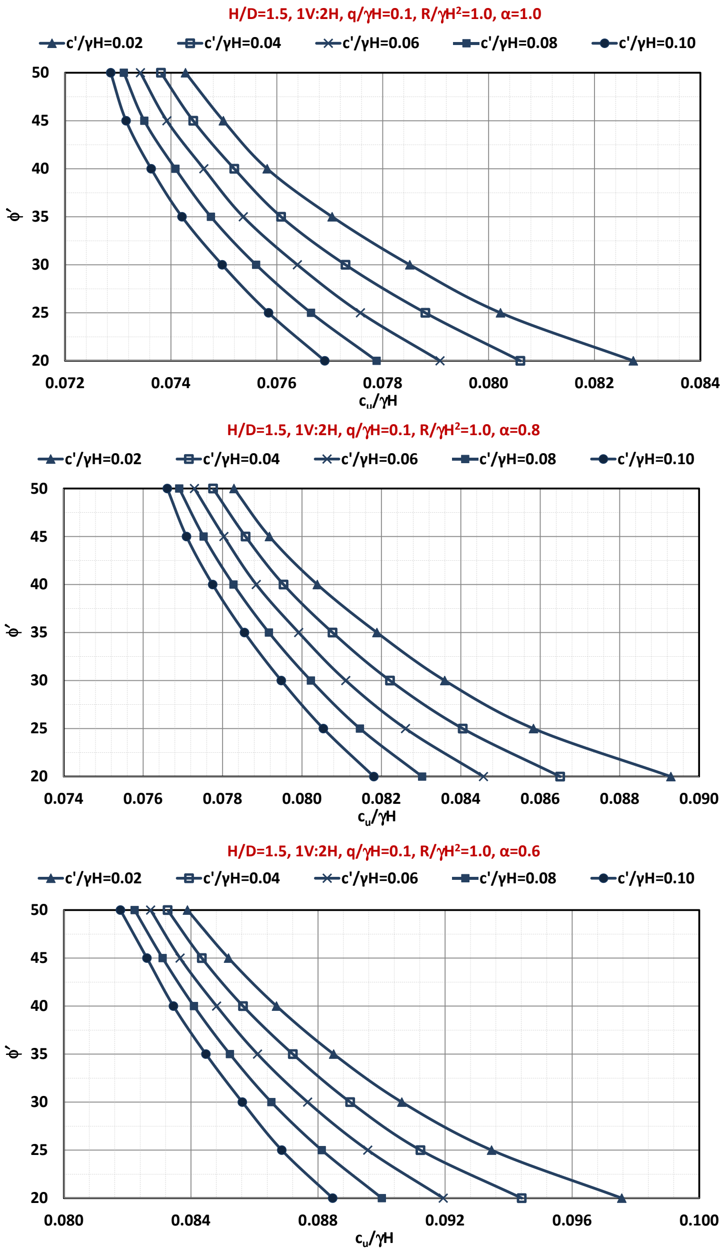

Figure 18: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=2, H/D=1.5.

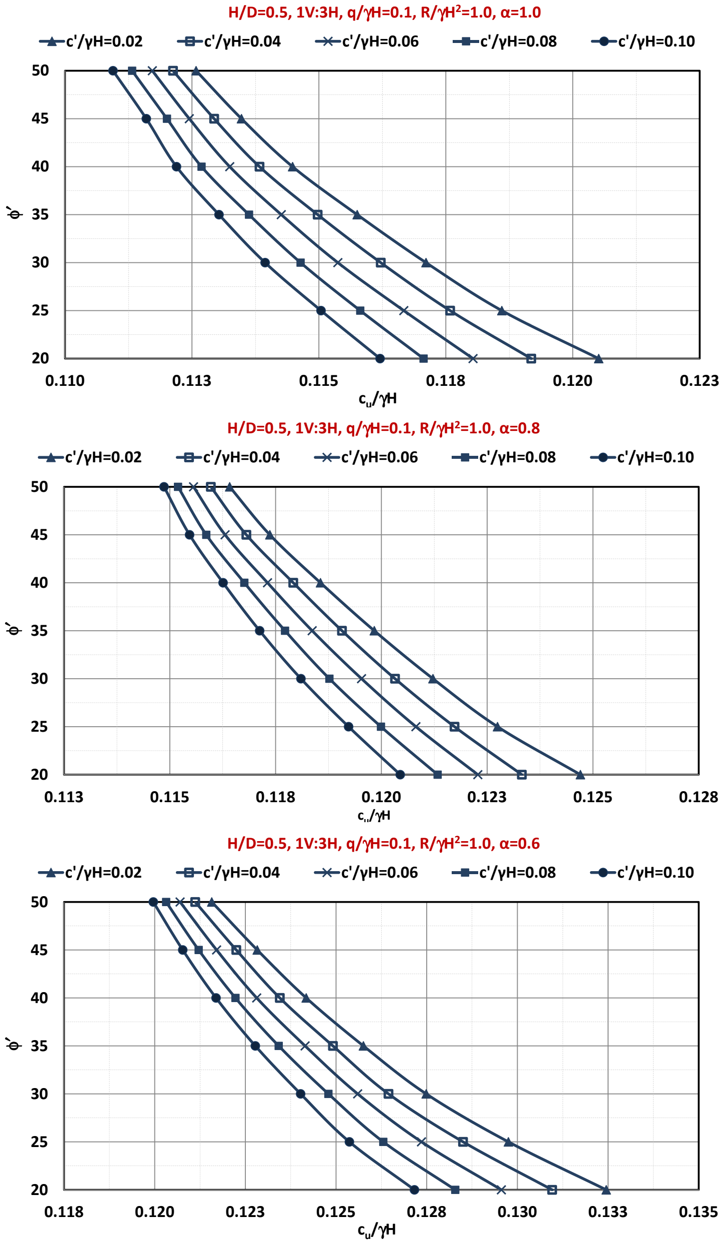

Figure 19: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=3, H/D=0.5.

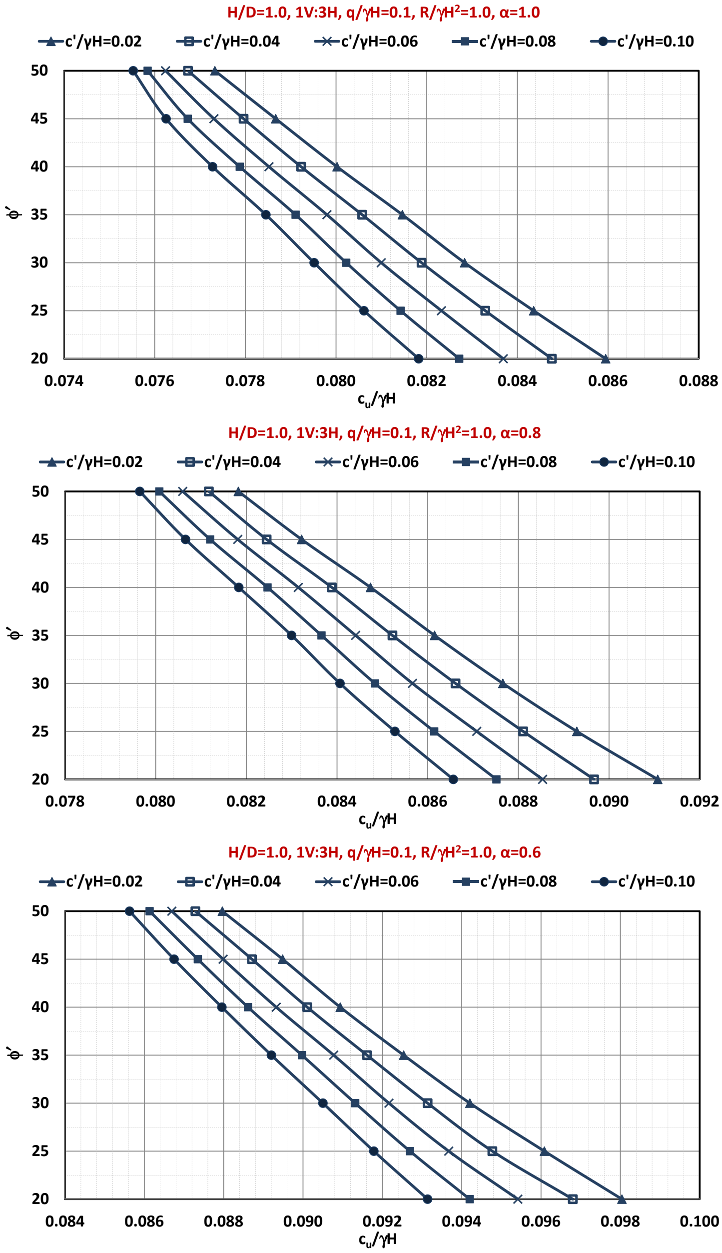

Figure 20: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=3, H/D=1.0.

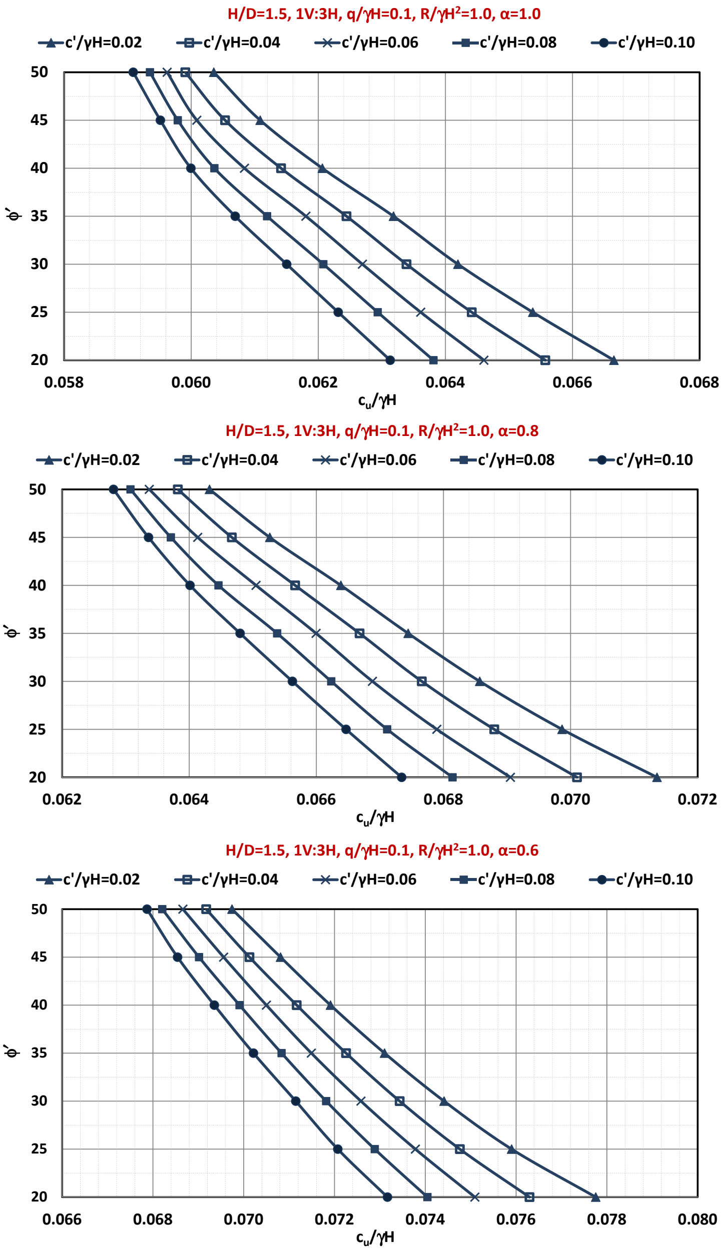

Figure 21: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=3, H/D=1.5.

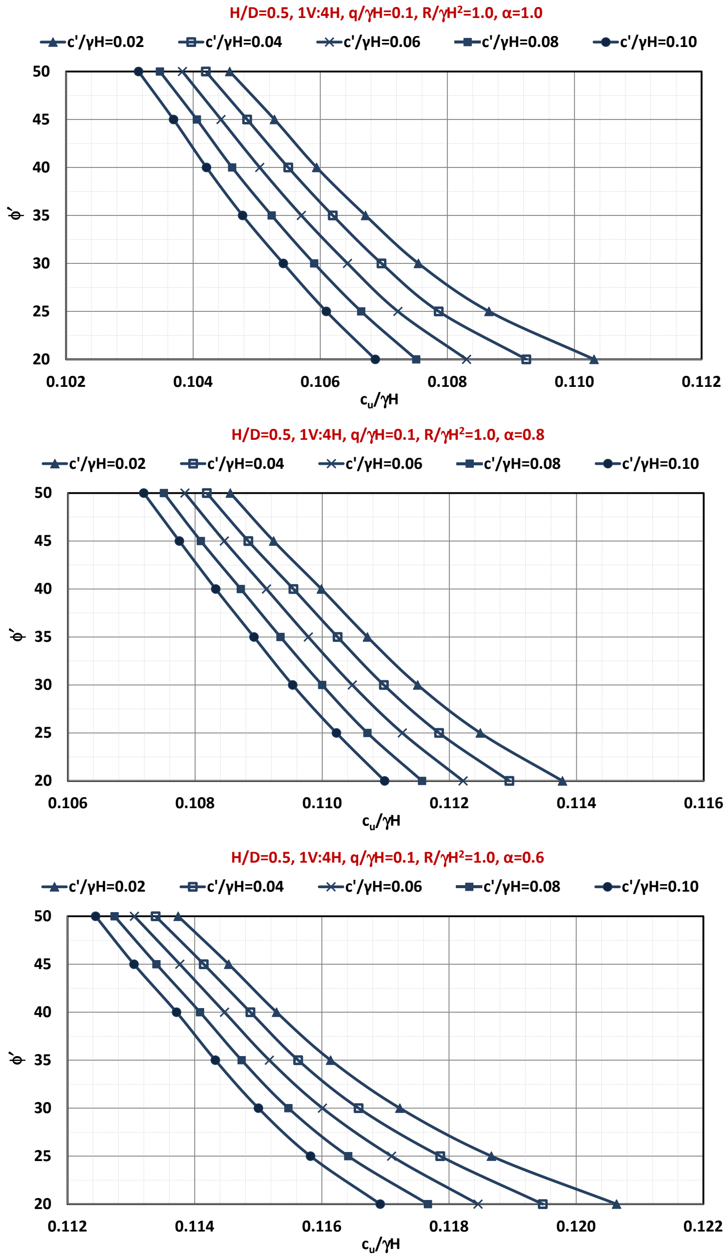

Figure 22: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=4, H/D=0.5.

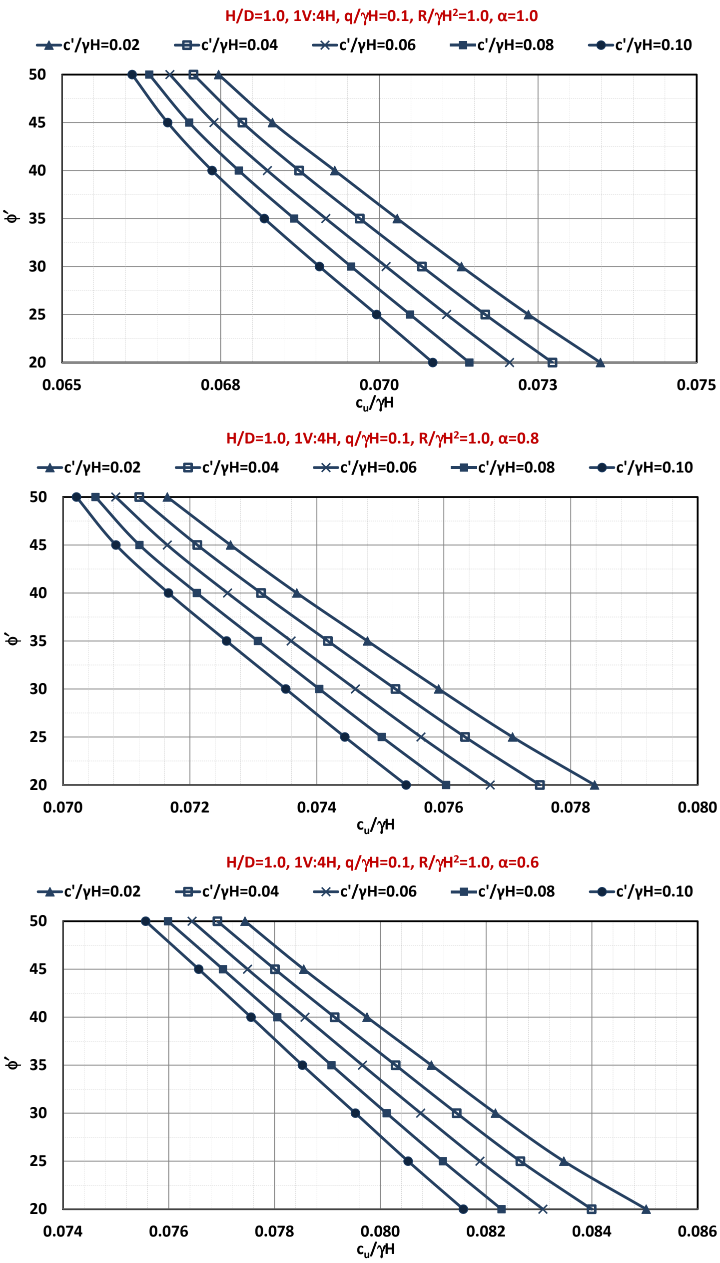

Figure 23: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=4, H/D=1.0.

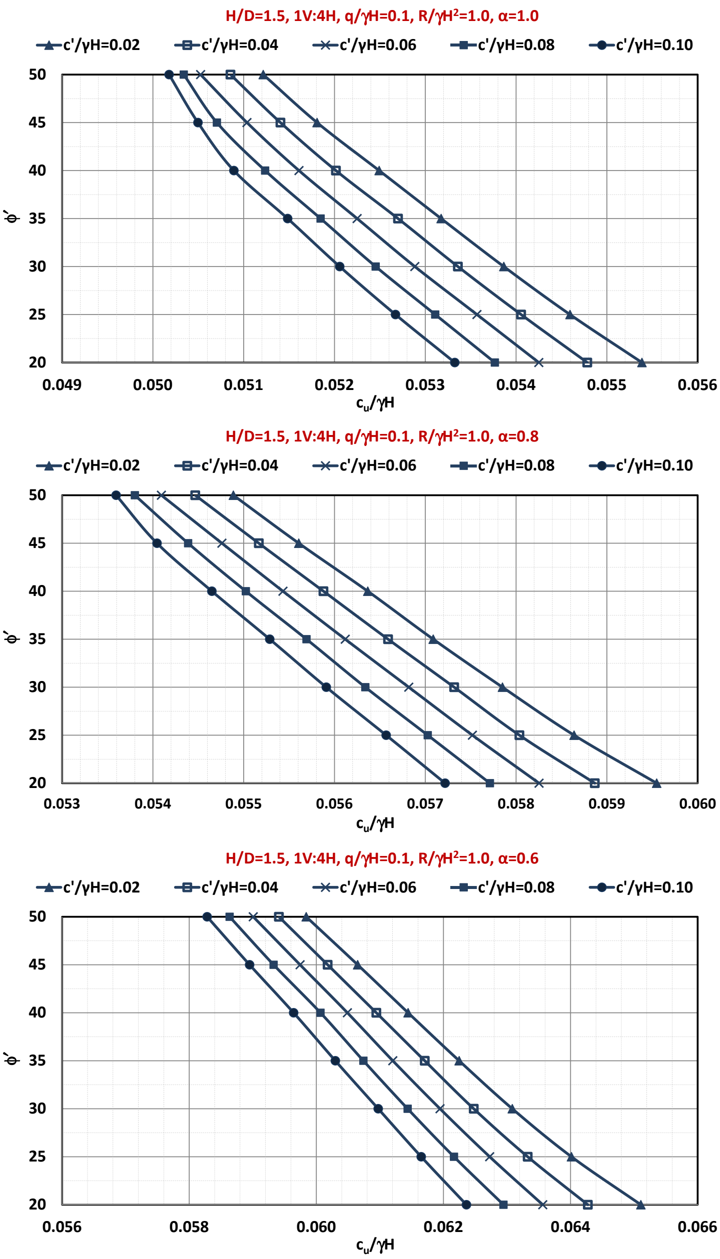

Figure 24: Required soil properties for embankment with surcharge and high rupture strength reinforcement n=4, H/D=1.5.

4. Design charts plotting $c_u/\gamma H$ vs $R/\gamma H^2$ for various values of H/D

The following charts present the relationship between the normalised undrained shear strength of the soft soil required for stability plotted against normalised reinforcement strength.

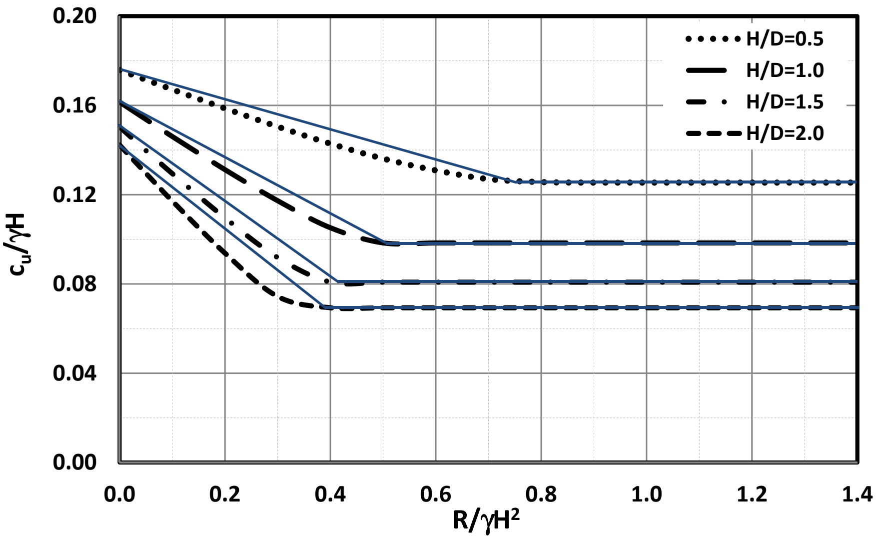

Figure 25: Required undrained shear strength for stability plotted against reinforcement strength for $c'/\gamma H = 0$, $\phi' = 30^o$, 1V:2H, and $\alpha = 0.8$. Thin lines indicate a bilinear fit. The maximum error in using this fit occurs approximately between $0.5 - 0.6R_L$ and is around 8% in $c_u/\gamma H$ or 20% in $R/\gamma H^2$, where R_L is the limiting (lowest) value of R for any curve.

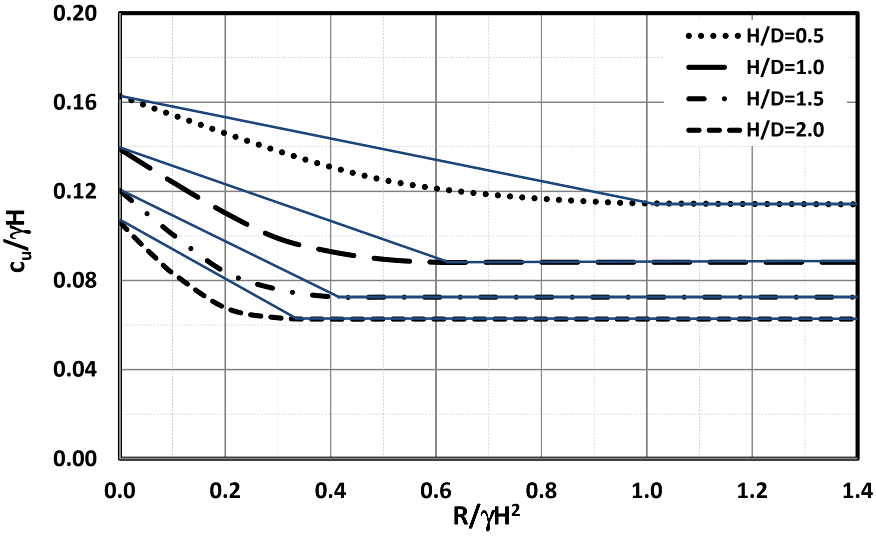

Figure 26: Required undrained shear strength for stability plotted against reinforcement strength for $c'/\gamma H = 0.1$, $\phi' = 50^o$, 1V:2H, and $\alpha = 0.8$. Thin lines indicate a bilinear fit. The maximum error in using this fit occurs approximately between $0.5 - 0.6R_L$ and is around 15% in $c_u/\gamma H$ or 60% in $R/\gamma H^2$, where R_L is the limiting (lowest) value of R for any curve.