INCREASED SHEAR STRENGTH IN FRICTIONAL SOIL

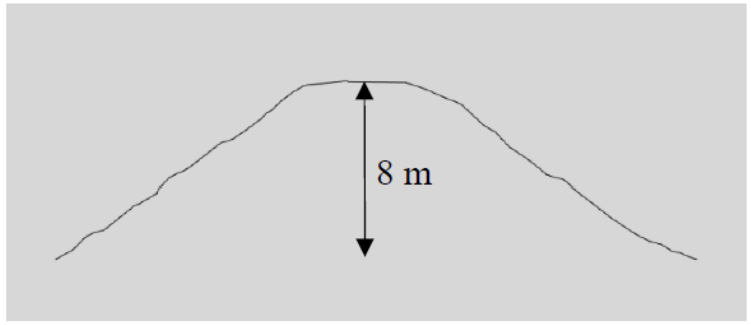
Qi Jia

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Background

Inlandsbanan





Östersund -Sveg *BDL 264 472+000.*

Slope angle: 36° > ϕ' =30° -35° (Gravelly sand)

↓

LEA FoS <1

Yet stable with current traffic load of 34kPa

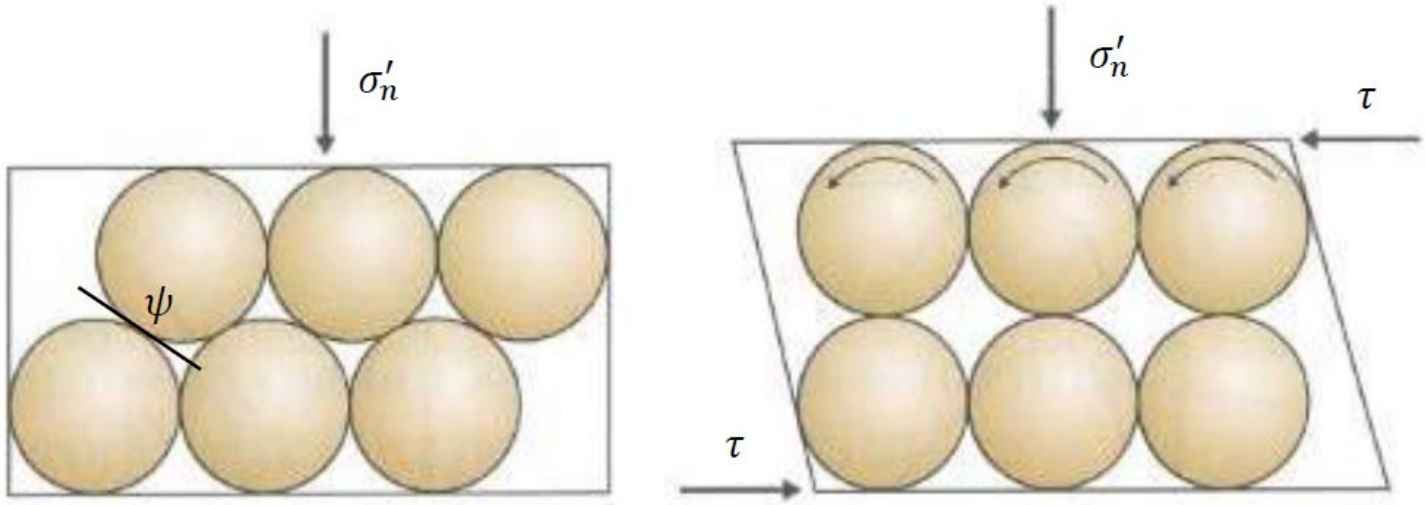
Cohesion is introduced: $\tau_f = c' + \sigma' \tan\phi'$ to capture increased strength

Yet no cohesion in frictional soil

Increased shear strength in firctional soil due to: dilatancy and capillary suction

Aim of the project: Stability analysis with consideration of dilatancy and suction

Dilatancy



(From Axelsson and Mattsson, 2016)

$$\phi' = \phi'_{cv} + \psi$$

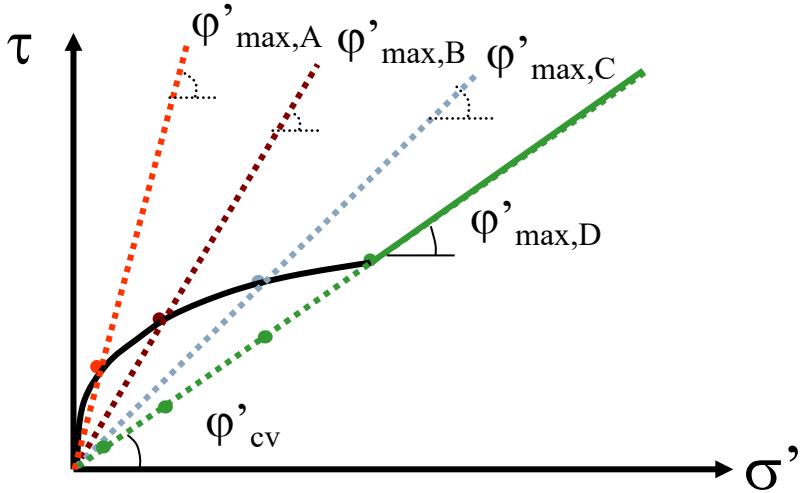
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Extra friction angle

Dilatancy

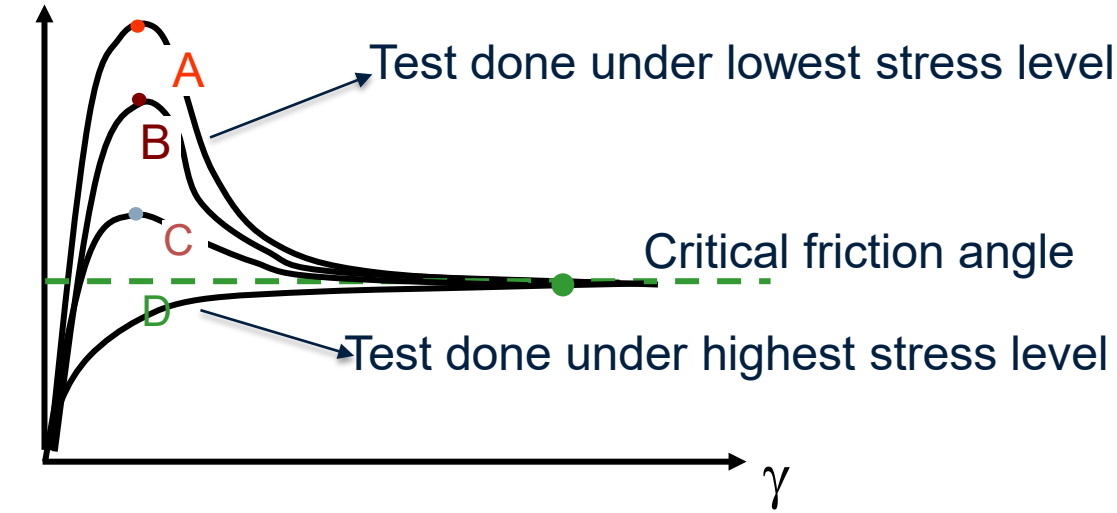
Compaction degree
Lose soil: low dilatancy, dense soil: high diltancy

Stress level
low stress level: high dilatancy, high stress level: low diltanacy



Shear strength as a function of stress state

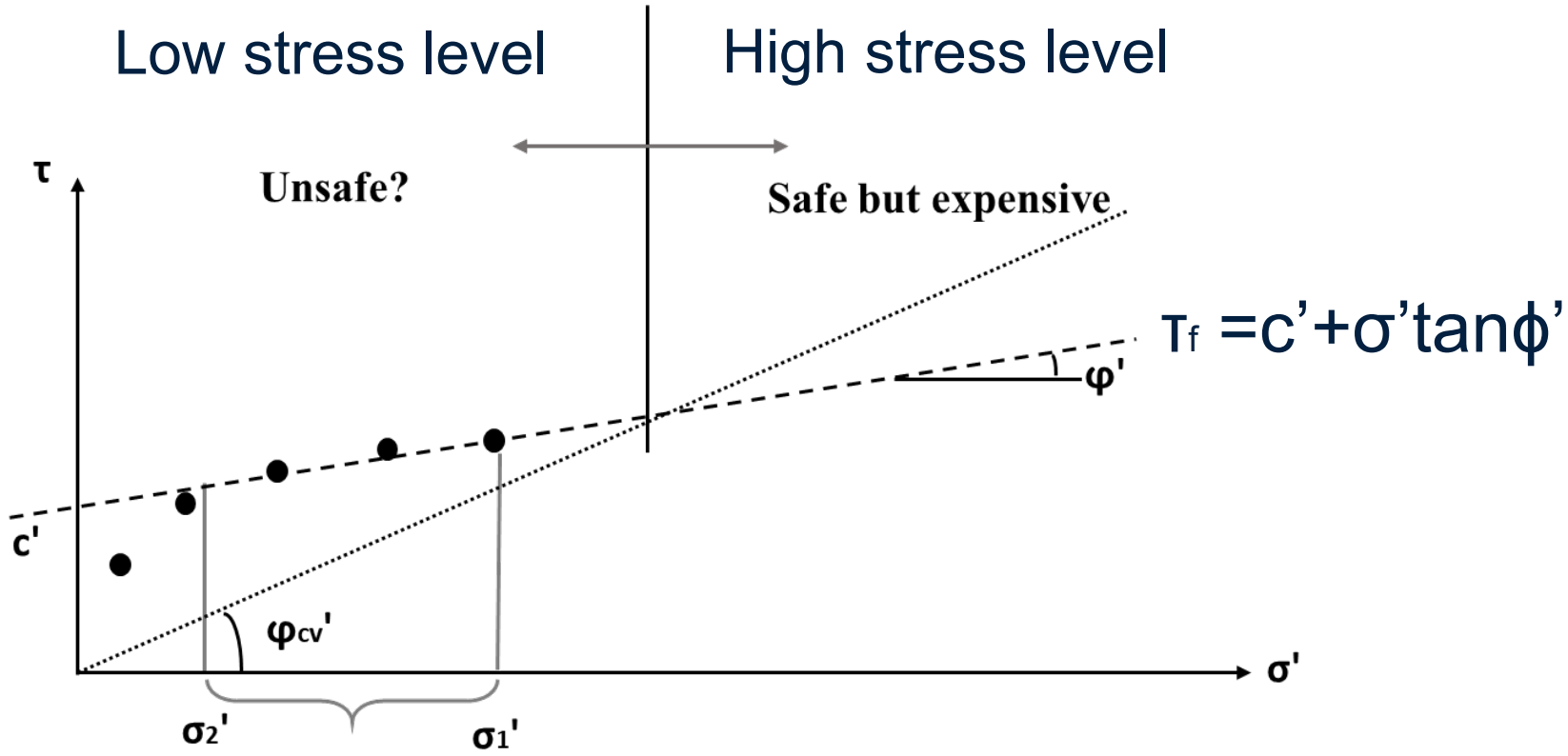
φ' = arctan (τ/σ')



Mobilised friction angle as function of shear strain

$\tau_f = c' + \sigma' \tan\varphi'$ But which c', φ' to choose

Dilatancy

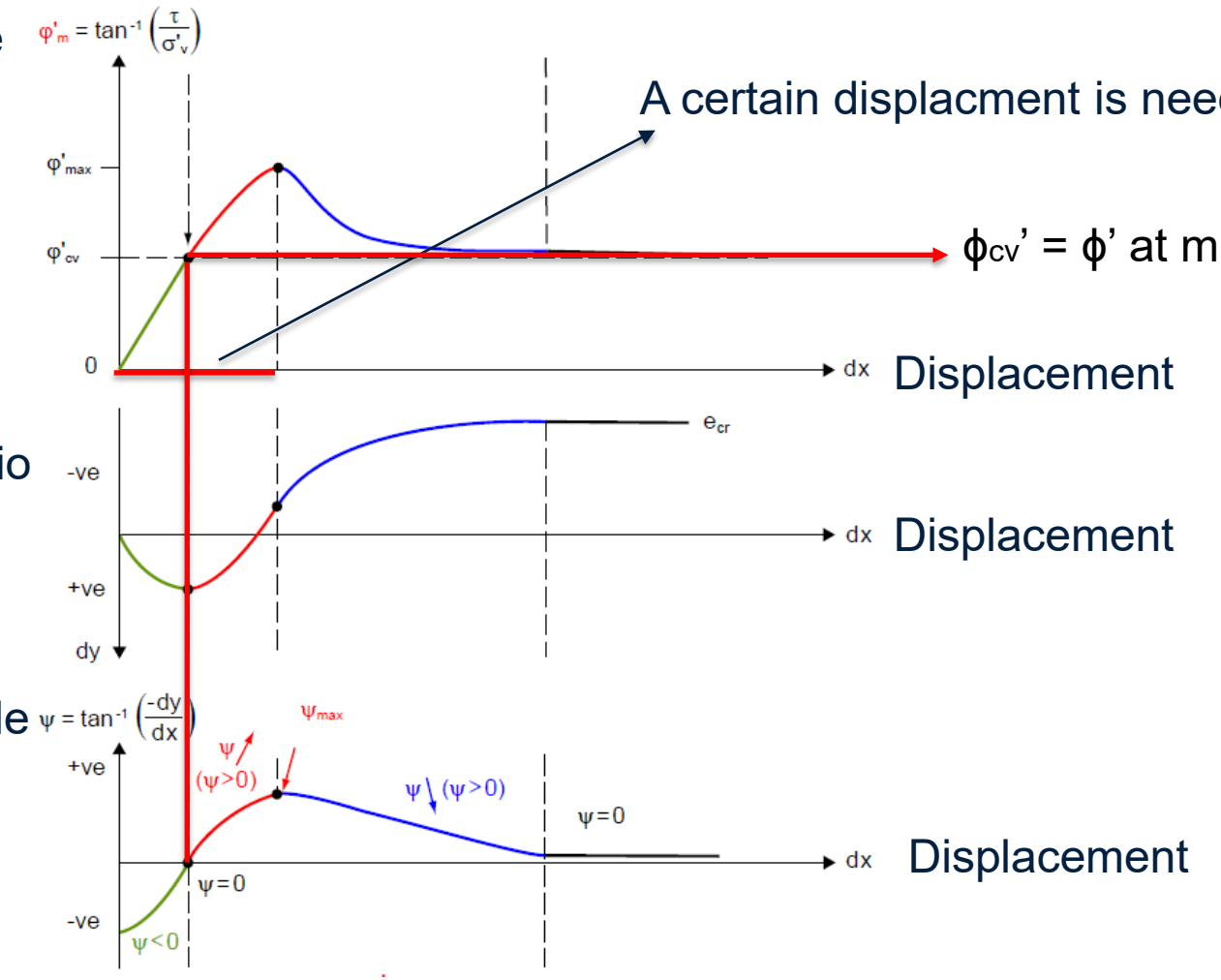


$\tau_f = c' + \sigma' \tan\phi'$

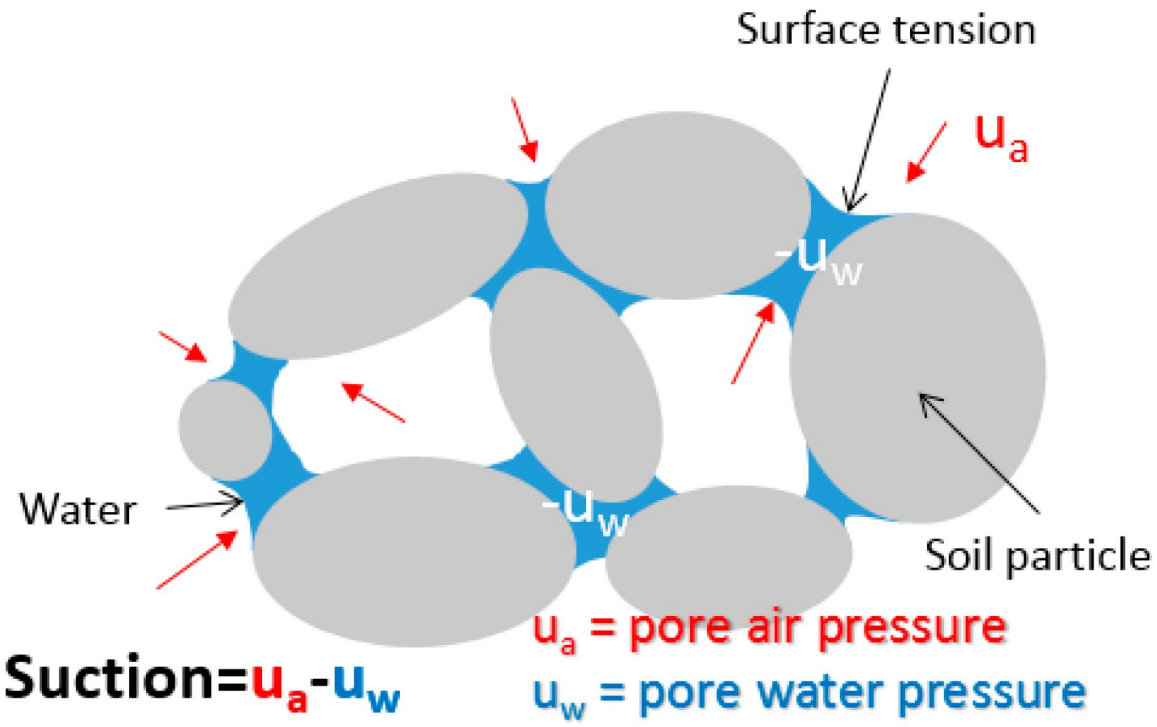
$\tau_f = c' + \sigma' \tan\phi'$, but which c', ϕ' to choose

Dilatancy

Mobilised friction angle



Capillary suction



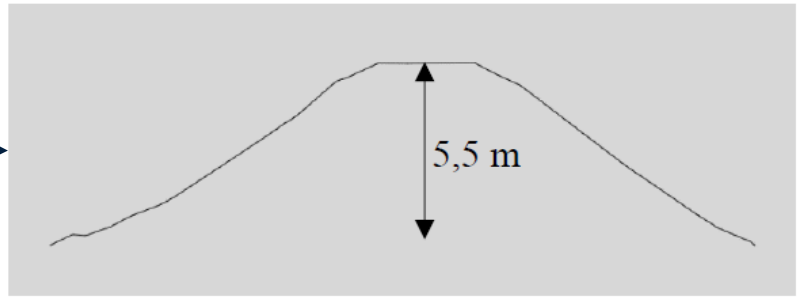
Principle for capillary suction (Chen, 2018).

Stability analysis (Master thesis by Carl Wallmark)

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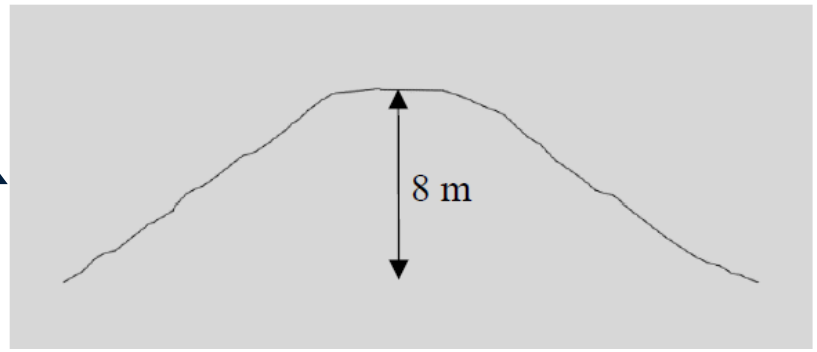


”High steep embankments”



Arvidsjaur-Storuman BDL 164 193+480

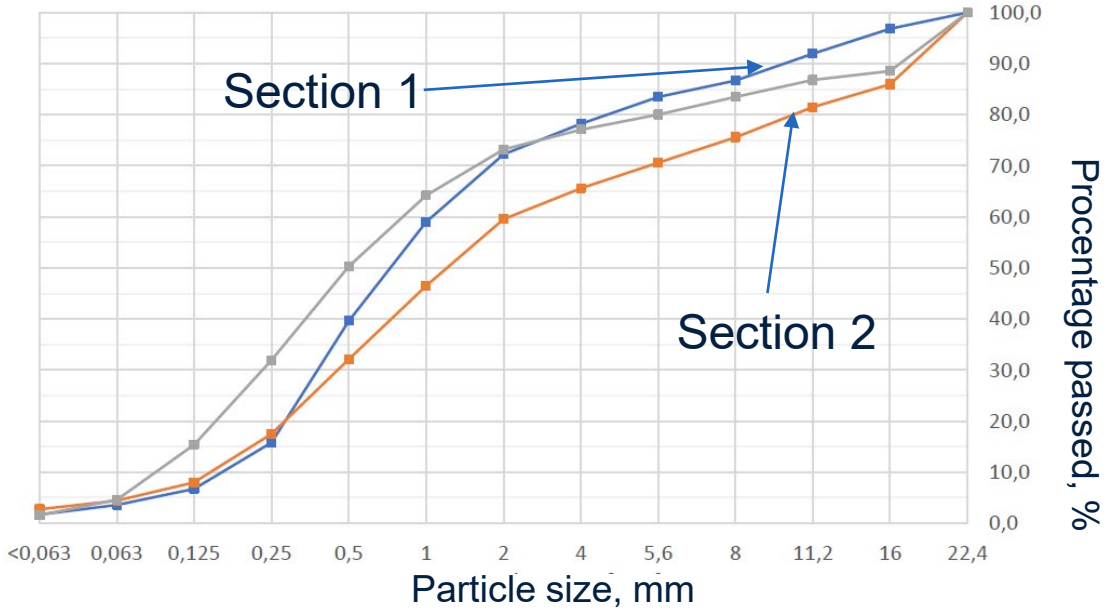
Section 1



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Section 2

Some material parameters

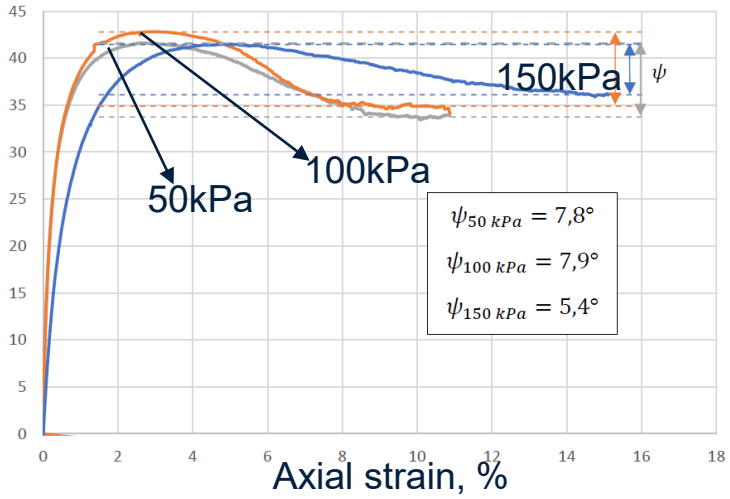


Gravelly sand

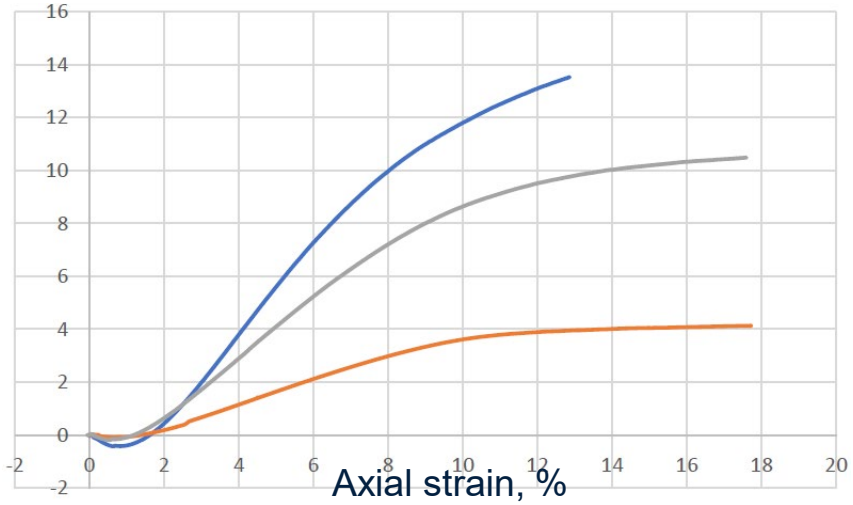
	Section 1	Section 2
Max. dry density, t/m3	2.01	2.24
Optimal water content, %	7	5.7
Degree of compaction, %	81.6	80.2
Natural water content, %	2.2	4.2
Degree of saturation	0.095	0.24

Result triaxial test (material from section 2)

Mobilised friction angle ϕ, °



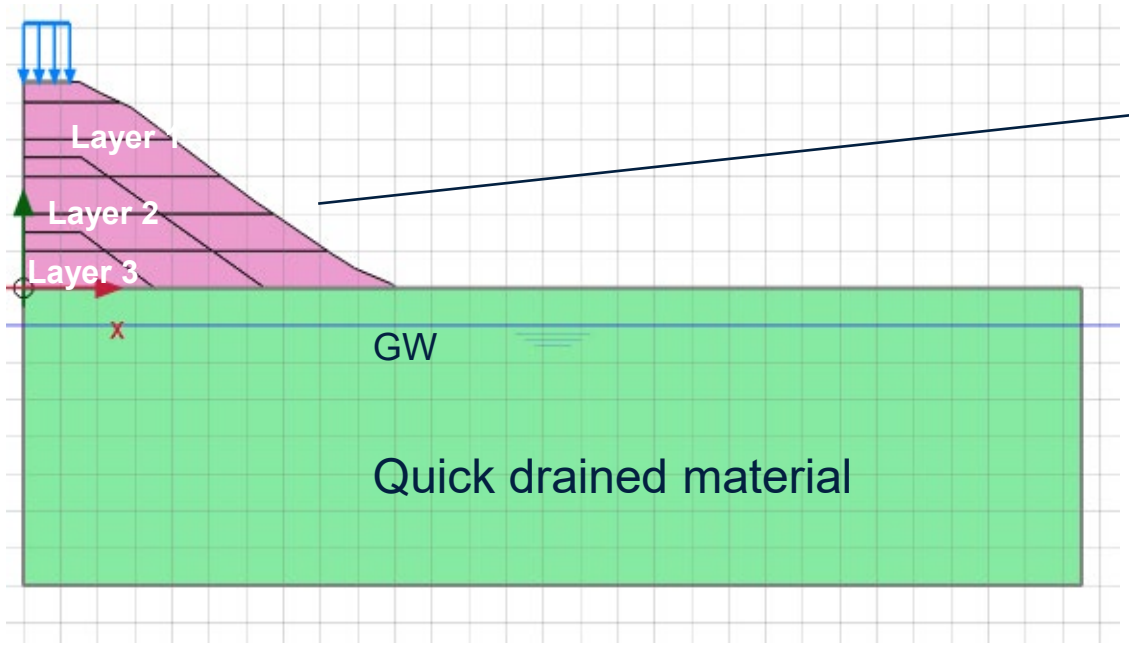
Volumetric strain, %



There is a certain dilatancy available which must be considered when doing stability analysis

	50kPa	100 kPa	150kPa
E_{50}, MPa	44.26	33.63	22.91
Critical friction angle, °	35		
Dilatancy angle, °	7.8	7.9	5.4
Max. friction angle, °	41.6	42.8	41.5
Mean friction angle, °	37.6	38.9	38.8

Stability analysis with considerration of dilatancy



Plaxis 2D model for section 1, layer depth 1.8m

Case 1: with the critical friction angle

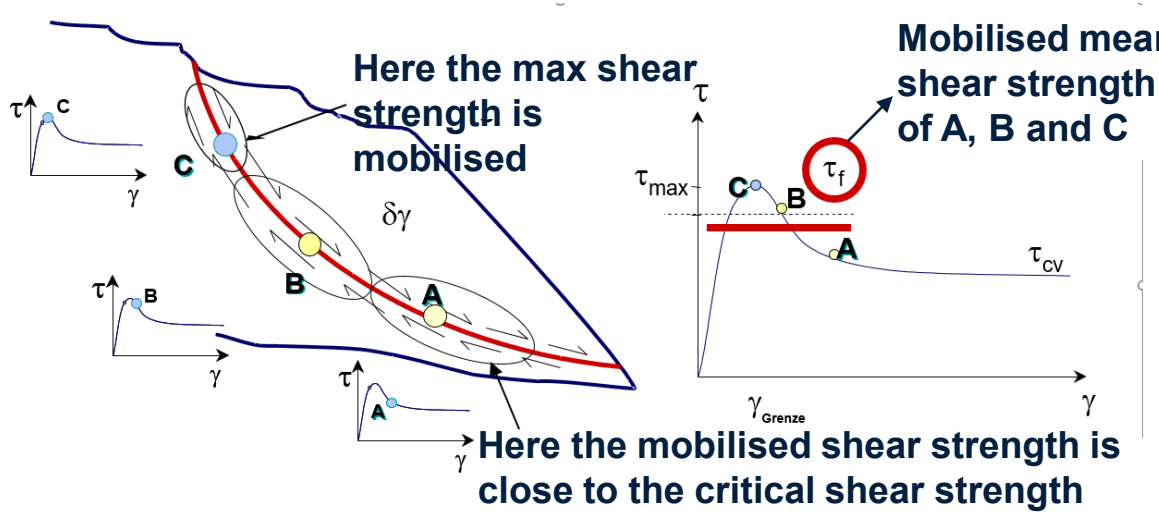
Case 2: with the mean friction angle
(dilatancy considered)

For bothe cases: current traffic load 34kPa
future traffic load 44kPa

	50kPa (layer 1)	100 kPa (layer 2)	150kPa (layer 3)
E_{50}, MPa	44.26	33.63	22.91
Critical friction angle, °	35		
Dilatancy angle, °	7.8	7.9	5.4
Max. friction angle, °	41.6	42.8	41.5
Mean friction angle, °	37.6	38.9	38.8

Other input parameters are from the literature
Cohesion: 1kPa

Calculated FoS with consideration of dilatancy



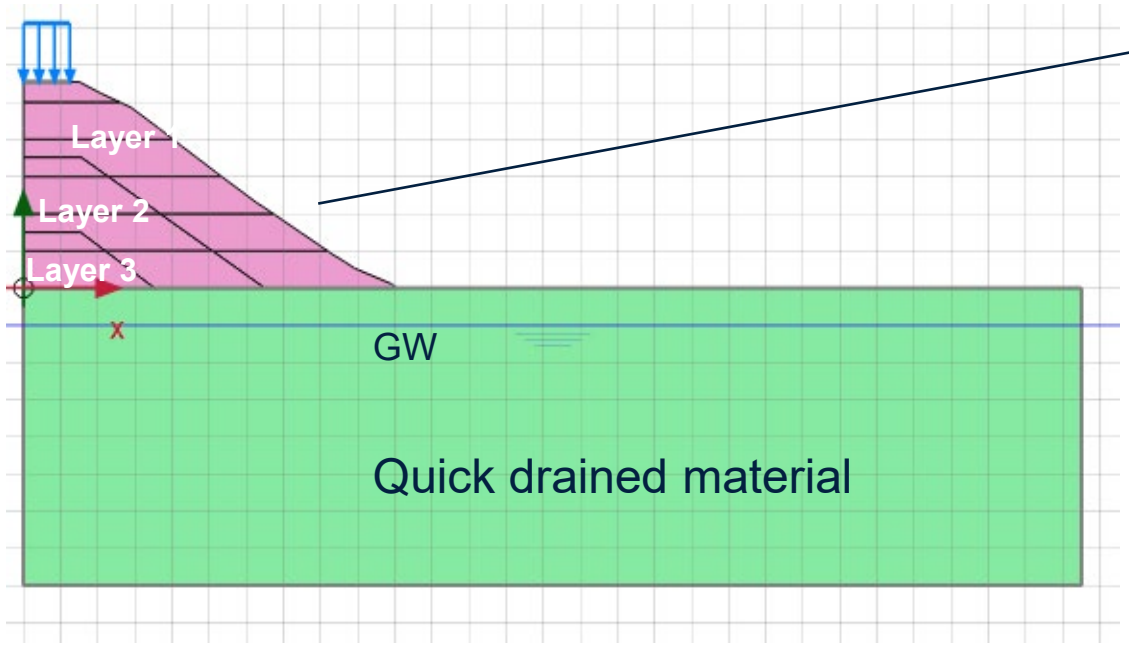
If the layer thickness is small enough, max friction angle could be used

	Section 1			Section 2		
	FoS critical (case 1)	FoS mean (case 2)	Increased by	FoS critical (case 1)	FoS mean (case 2)	Increased by
Current load 34 kPa	1.08	1.23	14%	1.09	1.27	17%
Future load 44 kPa	1.04	1.20	15%	1.07	1.23	15%

Case 1: with the critical friction angle
Case 2: with the mean friction angle (dilatancy considered)

Conclusion: when dilatancy is considered the embankments are stable for both current and future traffic loads

Stability analysis with consideration of capillary suction



Plaxis 2D model for section 1, layer depth 1.8m

Case 1: with critical friction angle
cohesion on layer 1,2 and 3
Case 2: with critical friction angle
cohesion on layer 2 and 3
(represent heavy rainfall event)

For both cases: current traffic load 34kPa
future traffic load 44kPa

	50kPa (layer 1)	100 kPa (layer 2)	150kPa (layer 3)
E_{50}, MPa	44.26	33.63	22.91
Critical friction angle, °	35		
Cohesion,kPa	40 (result from water retention test)		

Other input parameters are from literature



Calculated FoS with considerration of capillary suction

	Section 1			Section 2		
	$FoS_{critical}$	$FoS_{critical+c}$ (case 1)	$FoS_{critical+c}$ (case 2)	$FoS_{critical}$	$FoS_{critical+c}$ (case 1)	$FoS_{critical+c}$ (case 2)
Current load 34 kPa	1.08	2.52	1.08	1.09	1.88	1.08
Future load 44 kPa	1.04	2.44	1.05	1.07	1.82	1.07

Case 1: with critical friction angle, cohesion on layer 1,2 and 3
Case 2: with critical friction angle, cohesion on layer 2 and 3
(represent heavy rainfall event or drought)

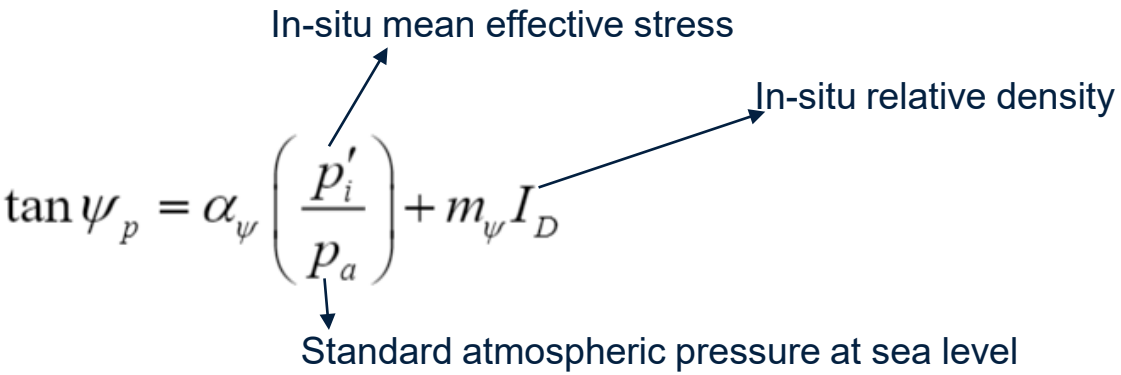
Conclusion: The effect of capillary suction disappers in case of heavy rainfall therefore should not be considered in stability analysis.

Conclusion

- When the dilatancy was considered, the result of stability analysis of studied embankments showed enough stability with the future traffic load.
- Increased shear strength due to capillarity should not be considered as capillary suction disappears under heavy rainfall.
- Max. friction angle can be used if layer thickness is small enough
- Dilatancy can be estimated with in-situ conditions

At the end

Cinicoglu and Abadkon (2015) extended the work of Bolten (1986) so that dilatation can be estimated with in-situ conditions :



Where α_ψ and m_ψ can be determined by two triaixal tests, and thus is possible to estimate friction angle and shear strength for all depths concerned

Appllication of the equation to materials other than sand need to be investigated

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