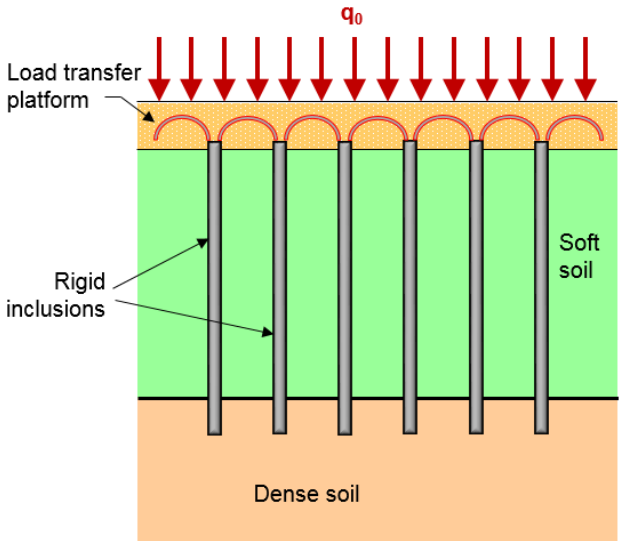
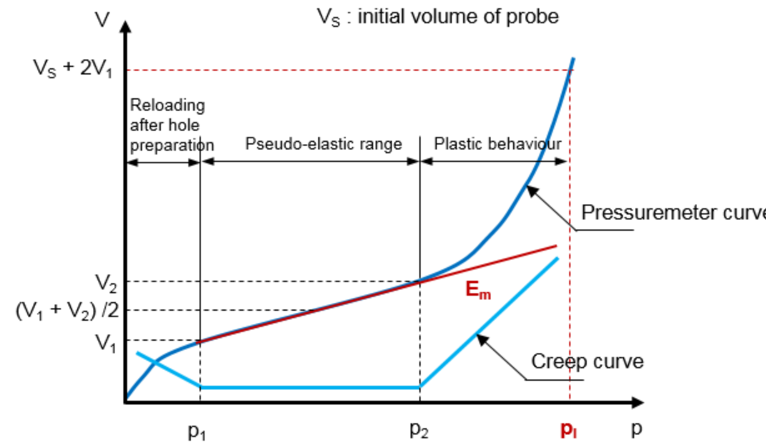
XVI ECSMGE 2015
13-17 September 2015 - Edinburgh





TC211 Workshop

Calibration of rigid inclusion parameters based on pressumeter test results

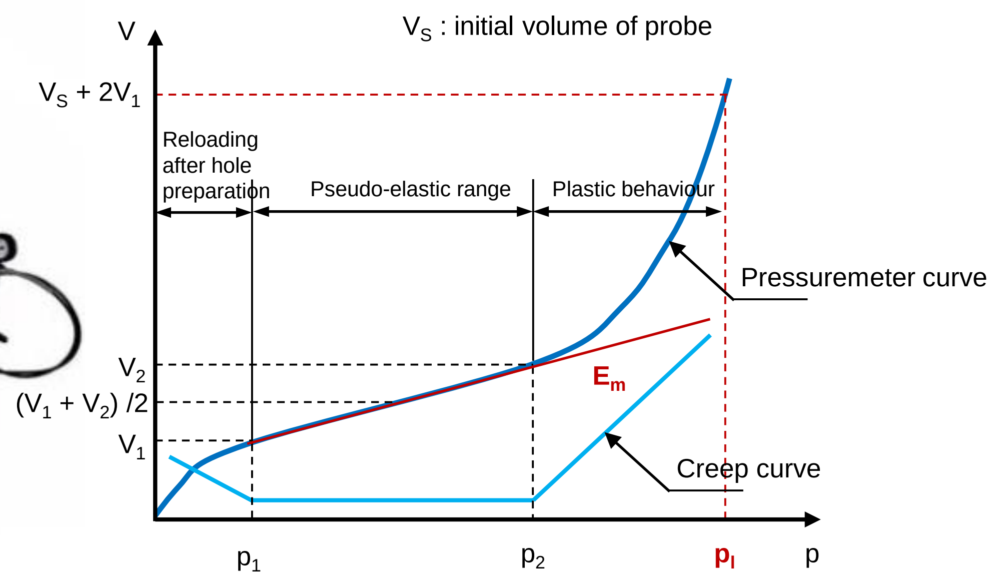
Jérôme Racinais

September 15,

Table of contents

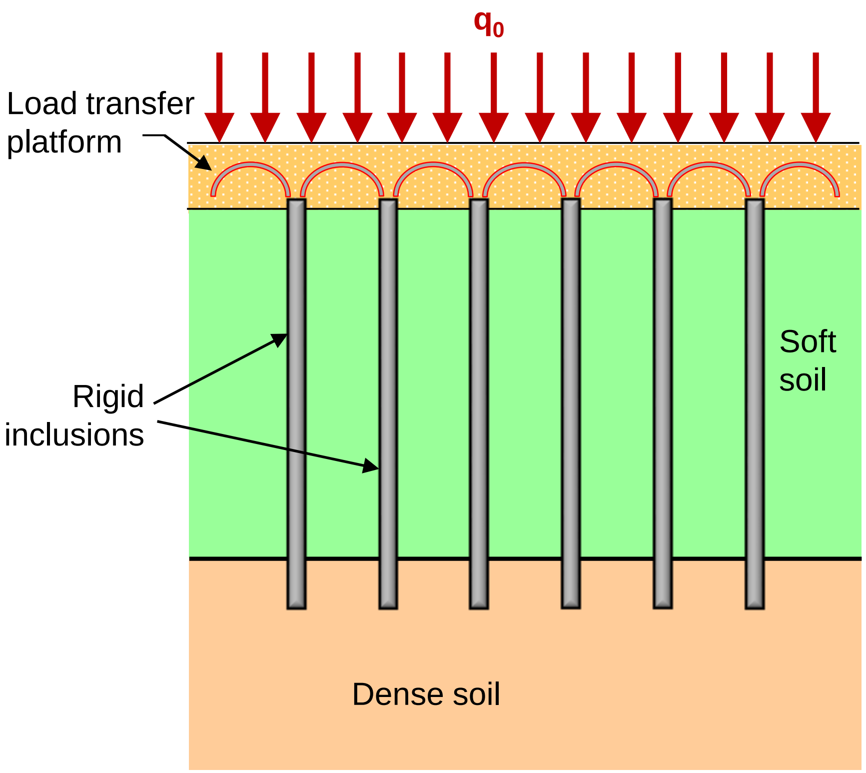
1. Reminder about pressuremeter tests

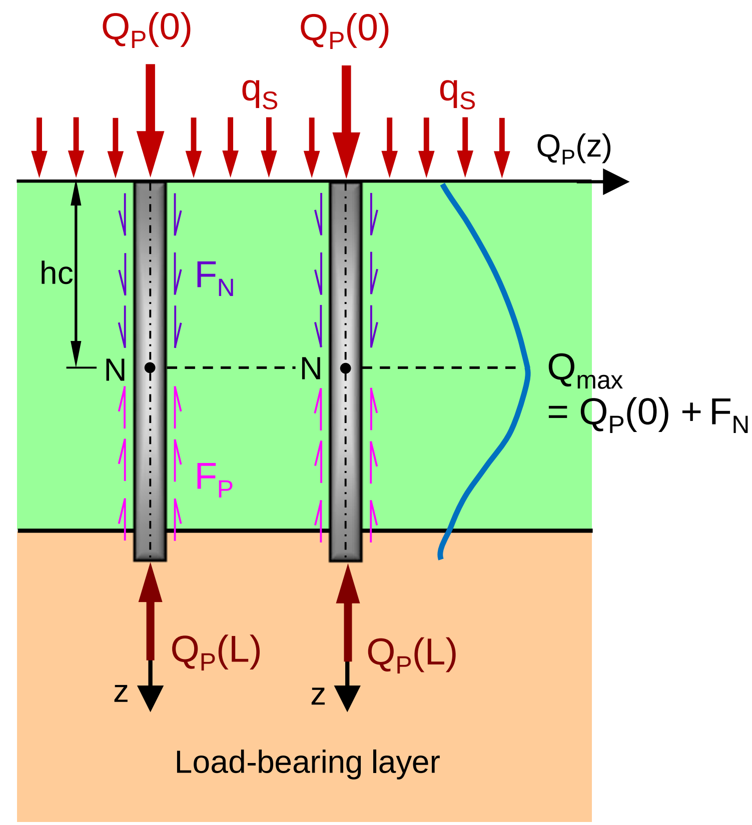
- **Determination of E_m and p_l**



$$E_m = 2(1+\nu)\left[V_S + \frac{V_1 + V_2}{2}\right] \times \frac{p_2 - p_1}{V_2 - V_1}$$

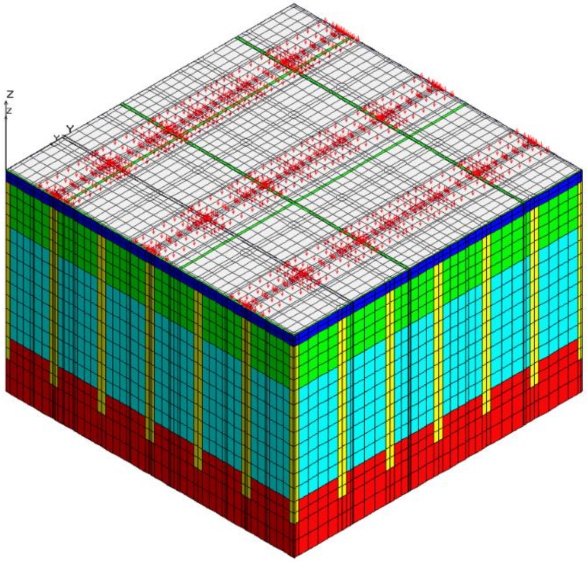
2. General behaviour of rigid inclusions

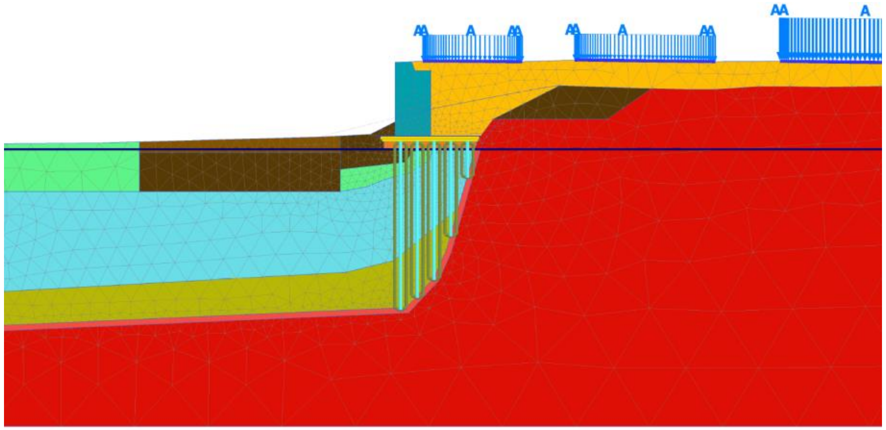


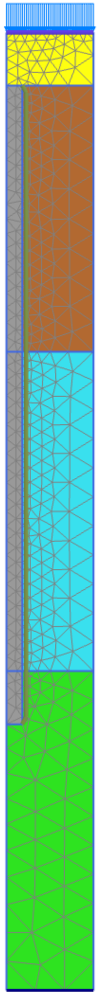


$$Q_P(0) + F_N = Q_{max} = F_P + Q_P(L)$$

3. Rigid inclusions design based on Finite Element Models





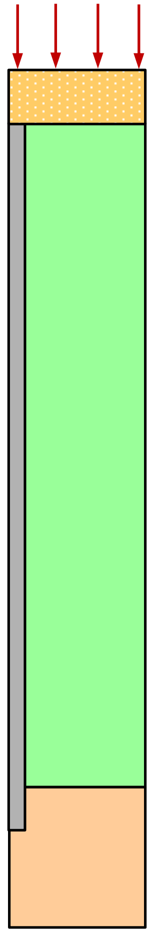


3. Rigid inclusions design based on Finite Element Models

- **Use of linear elastic perfectly plastic law with Mohr-Coulomb's failure criterion**

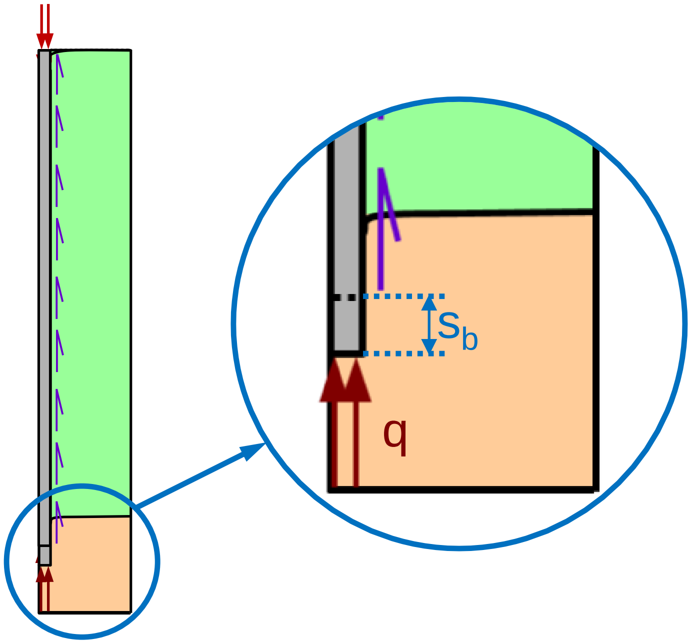
- **Main basic parameters**
  - Young's modulus E_Y
  - Poisson's ratio ν
  - Unit weight γ
  - Effective cohesion c'
  - Effective friction angle φ'

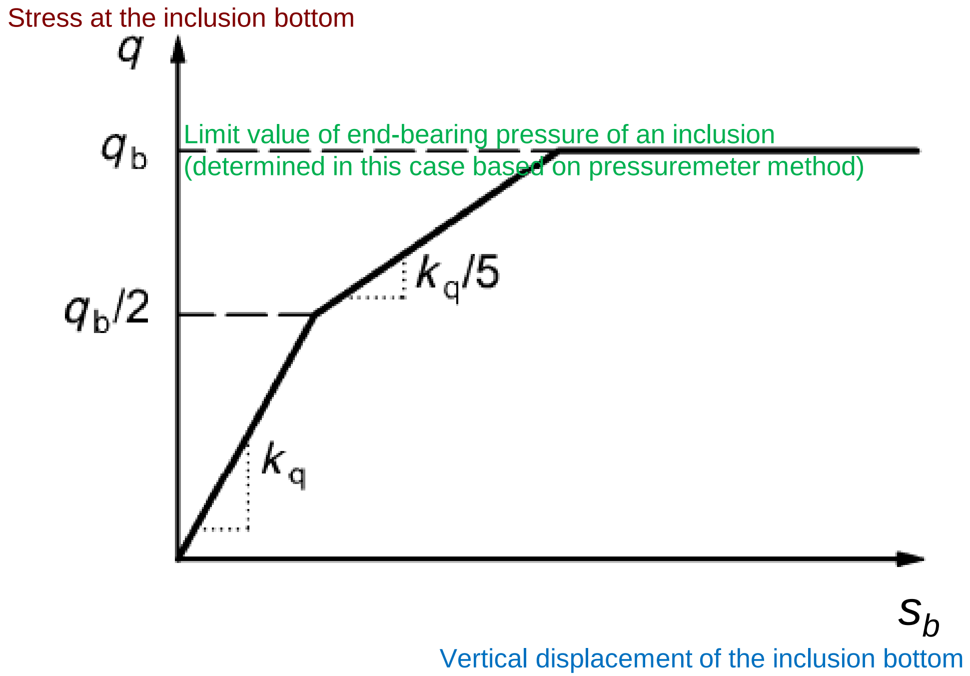
- **Which values should be input ?**
  - $\mathbf{E_Y = \frac{E_m}{\alpha}}$?
  - c' and φ' determined from lab tests ?



4. Semi-empirical mobilization laws of Frank and Zhao

- **Behaviour at the inclusion bottom**





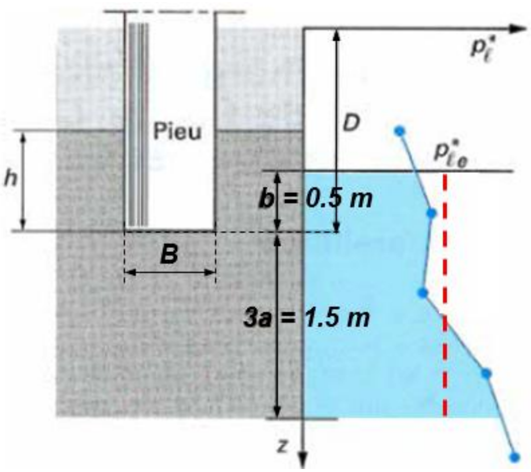
$$k_q = \frac{11E_M}{B} \text{ for fine-grained soils, } k_q = \frac{4.8E_M}{B} \text{ for granular soils}$$

B : inclusion diameter

- **Estimation of the limit end-bearing pressure: q_b (as per Appendix F of Standard NF P94-262)**

$$q_b = k_p p_{le}^*$$

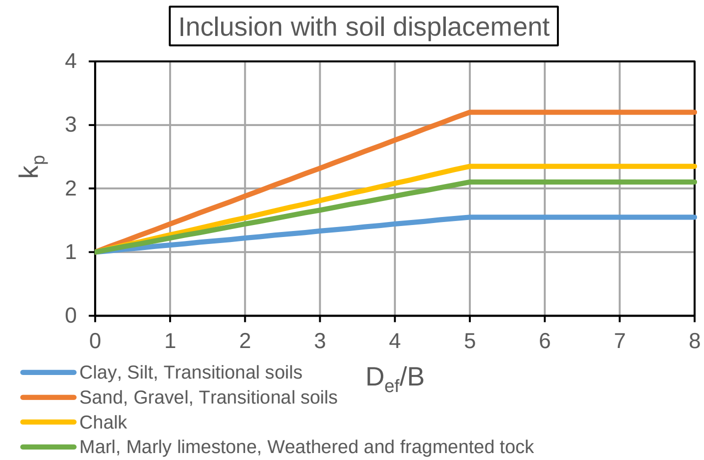
p_{le}^* : equivalent net limit pressure into the anchoring layer
k_p : pressuremeter bearing factor

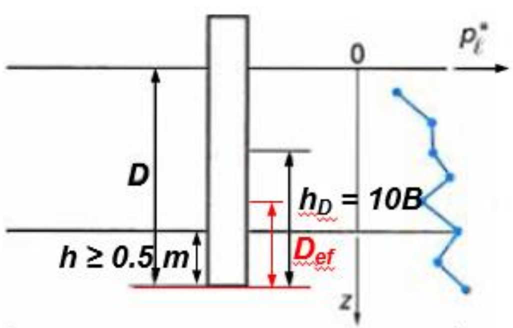


$$a = \max\left\{\frac{B}{2}; 0.5\right\} = 0.5\ \text{m}$$

$$b = \min\{a; h\} = 0.5\ \text{m}$$

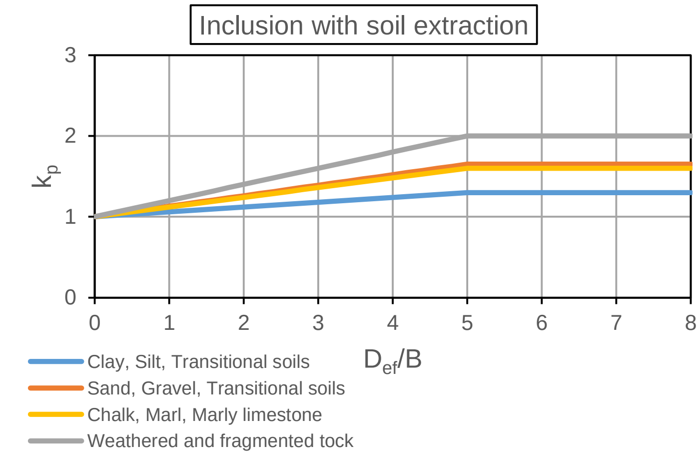
$$p_{le}^* = \frac{1}{b+3a}\int_{D-b}^{D+3a} p_l^*(z)dz$$





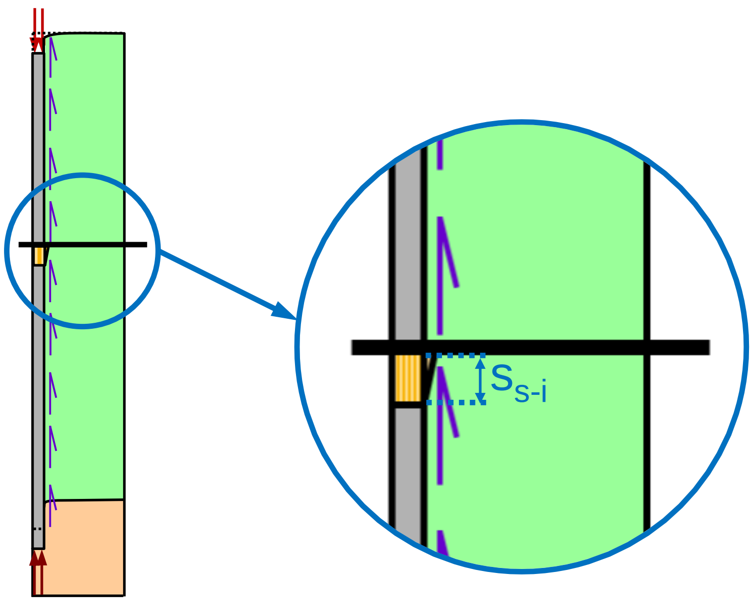
$$D_{ef} = \frac{1}{p_{le}^*}\int_{D-h_D}^{D} p_l^*(z)dz$$

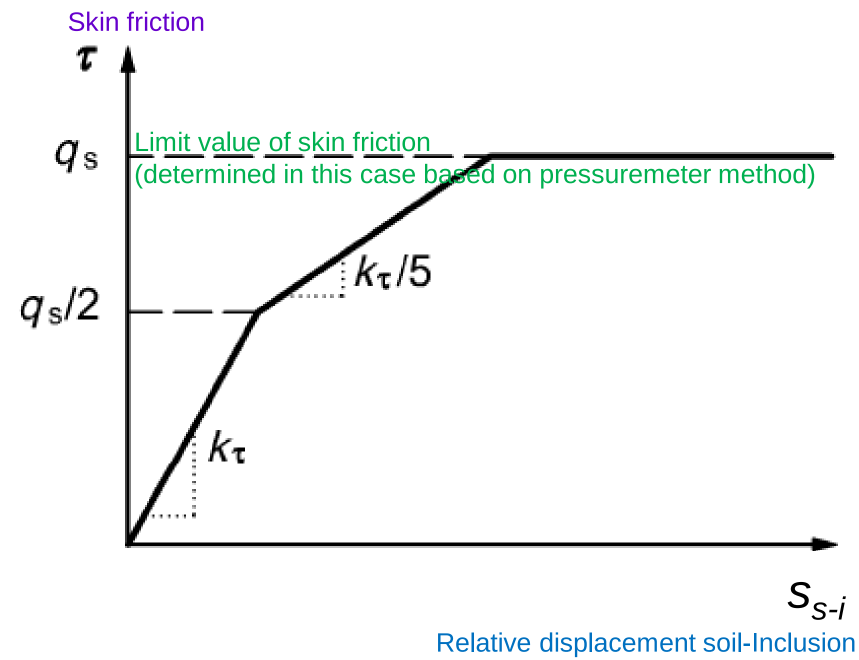
h_D = 10B (is comprised between 3 m to 4.2 m)



4. Semi-empirical mobilization laws of Frank and Zhao

- **Behaviour along the interface soil/inclusion**





$$k_\tau = \frac{2E_M}{B} \text{ for fine-grained soils, } k_\tau = \frac{0.8E_M}{B} \text{ for granular soils}$$

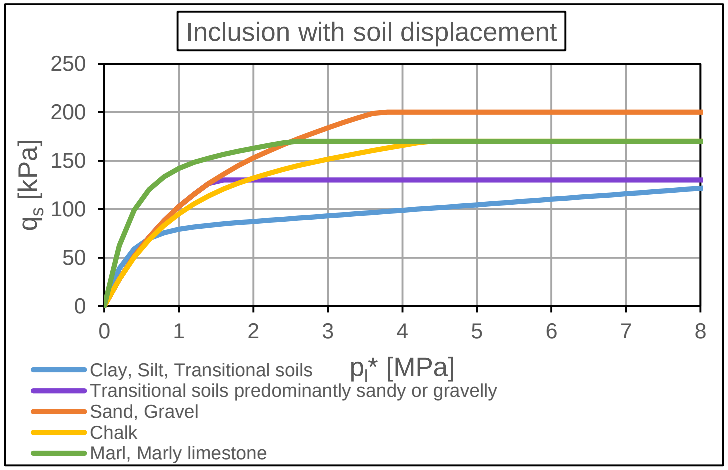
B : Inclusion diameter

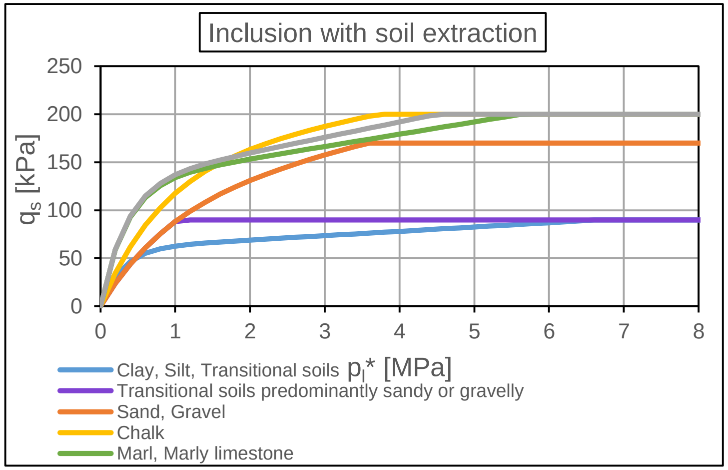
4. Semi-empirical mobilization laws of Frank and Zhao

- **Estimation of the limit skin friction: q_s (as per Appendix F of Standard NF P94-262)**

$$q_s = \min\{\alpha_{pieu-sol} \times f_{sol}(p_l^*); q_{s;max}\}$$

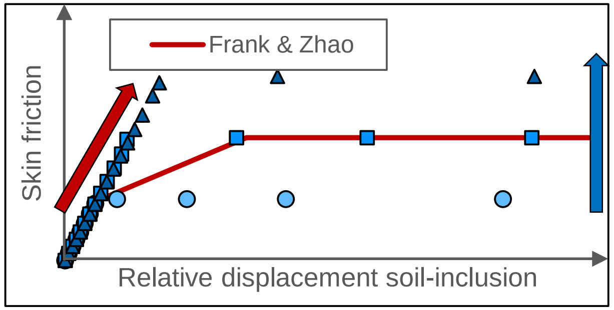
$\alpha_{pieu-sol}$: dimensionless parameter depending on pile type and soil type
f_{sol} : function depending on soil type and p_l^* value



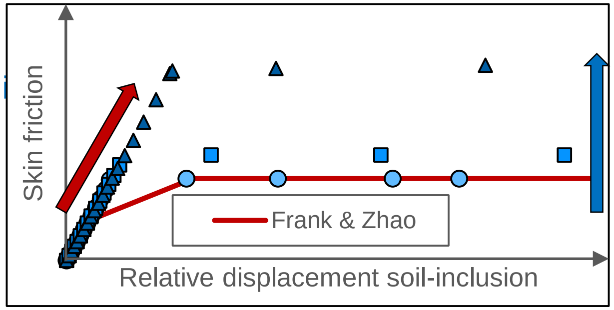


5. Calibration of FEM input parameters on Frank & Zhao's laws

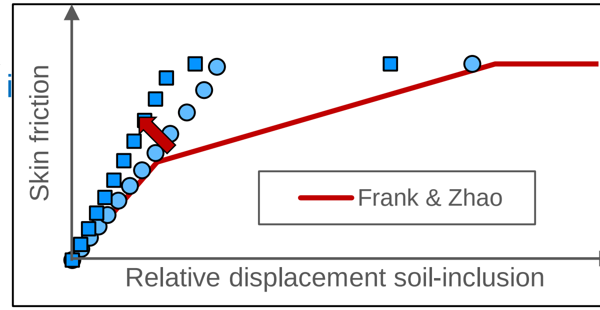
- **Skin friction (along the inclusion in surrounding soil)**



Effective cohesion c'

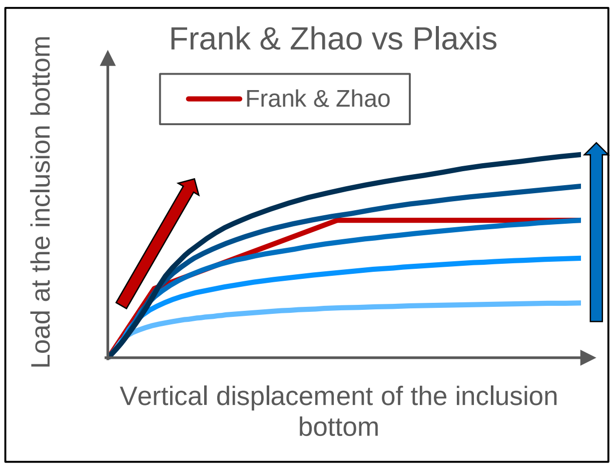


Friction angle φ'

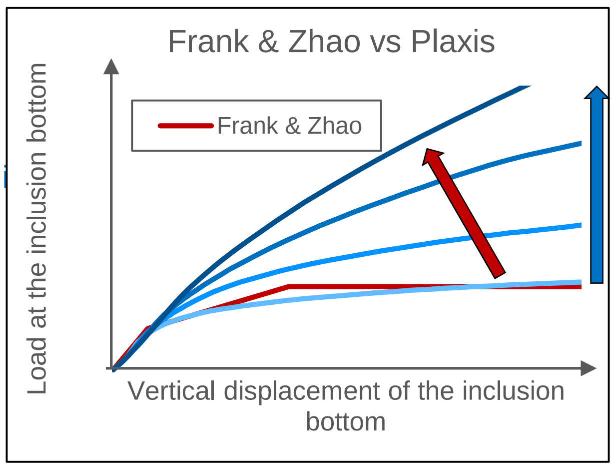


Young's modulus E_Y

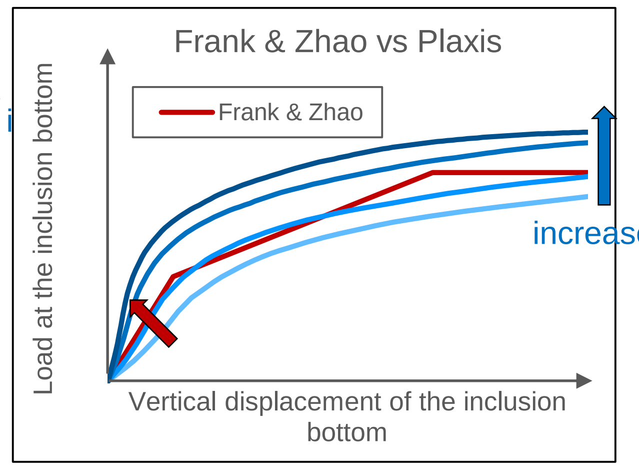
- **Load at the inclusion bottom (in the anchoring layer)**



Effective cohesion c'

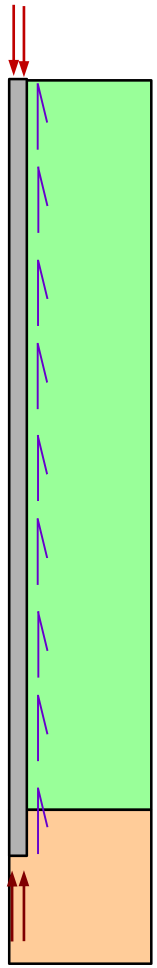


Friction angle φ'



Young's modulus E_Y

5. Calibration of FEM input parameters on Frank & Zhao's laws



$E_Y = E_m/\alpha$

c' = q_s (q_s determined based on pressuremeter method)

φ' ≈ 0°

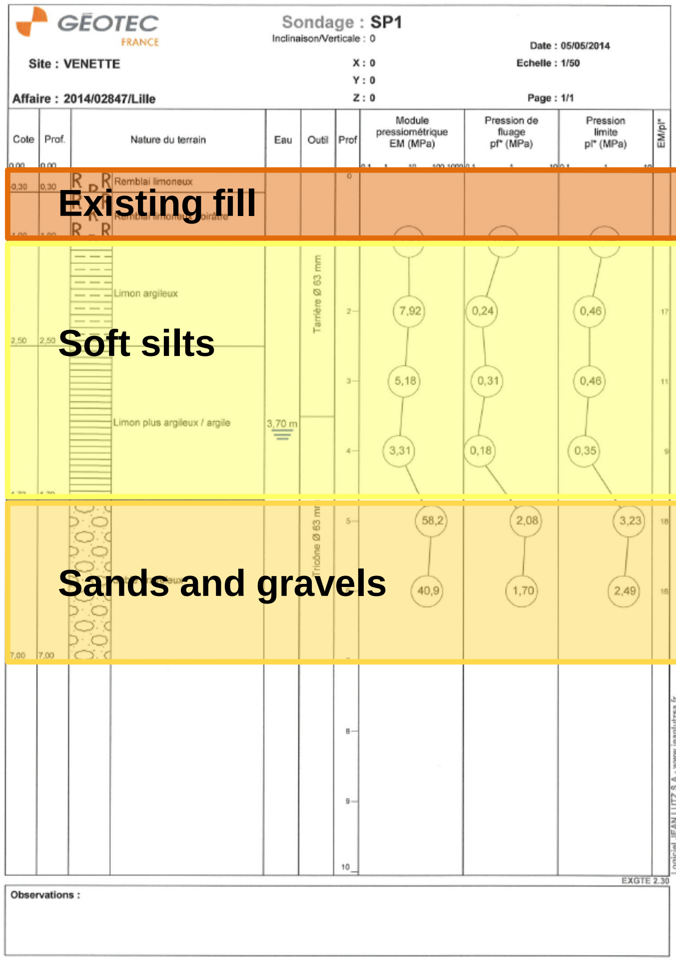
E_Y = 1.5 to 6 x E_m/α

c' = $q_b/9$ (q_b determined based on pressuremeter method), API (1991)

φ' ≈ 0°

6. Example: Plate Load Tests in Venette, France

- **Pressuremeter tests**



Thickness	Layer	E_m MPa	Pl MPa	α -	γ kN/m³	c' kPa	φ' °
1 m	**Existing fill**	15	0.96	1/2	20	11	25
4 m	**Soft silts**	5.5	0.43	1/2	20	6	31
4.5 m	**Sands and gravels**	35	2.50	1/3	20	0	43

From lab tests (γ, c', φ')

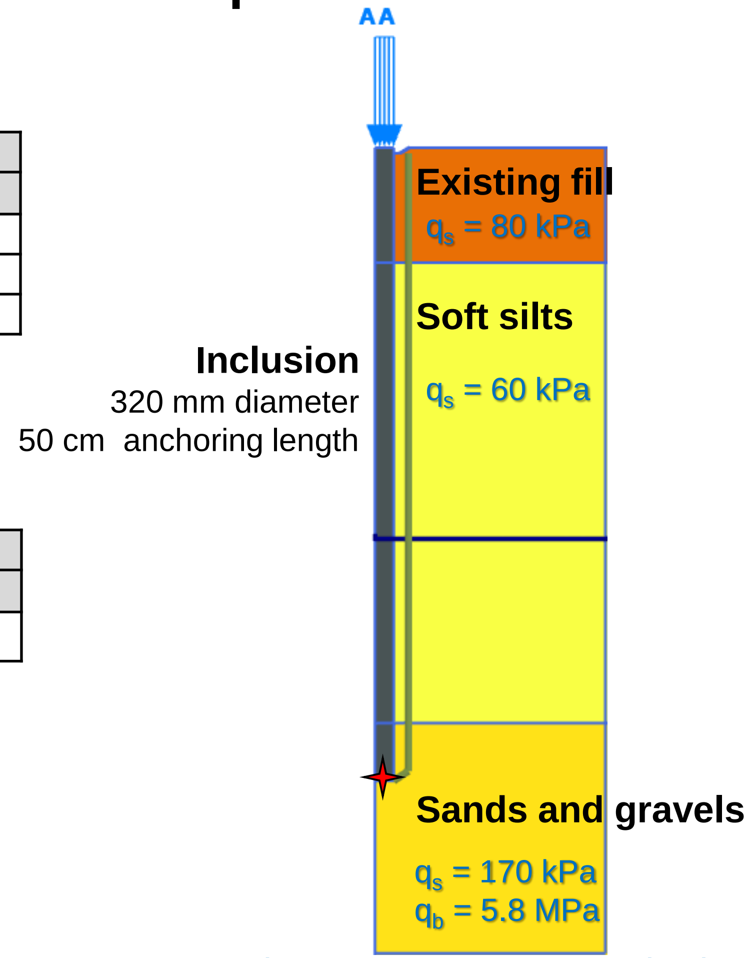
6. Example: Plate Load Tests in Venette, France

- **Presentation of the finite element model – initial parameters**
  - Skin friction

	γ	c'	φ'	E_Y	R_{inter}
	[kN/m³]	[kPa]	[°]	[MPa]	[-]
Fill	20	11	25	$= E_M/\alpha = 30$	1
Silts	20	6	31	$= E_M/\alpha = 11$	1
Interface Sands	16.5	0	43	$= E_M/\alpha = 105$	1

  - Inclusion bottom behaviour

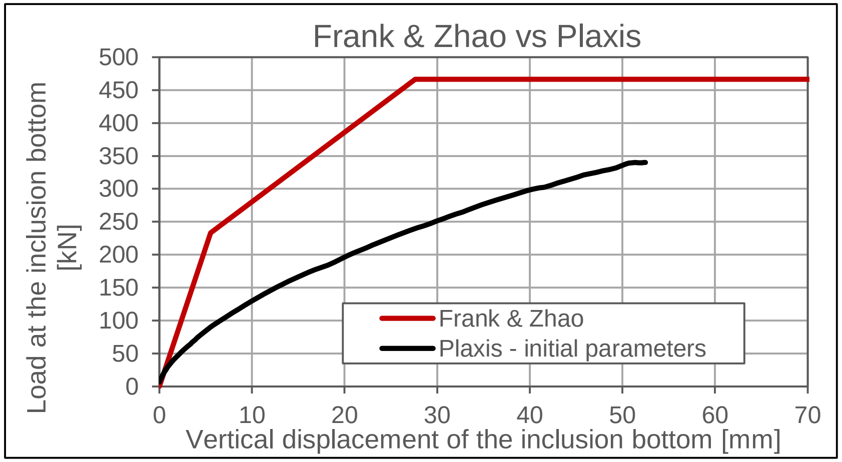
	γ	c'	φ'	E_Y
	[kN/m³]	[kPa]	[°]	[MPa]
Sands	16.5	0	43	$= E_M/\alpha = 105$



Based on pressuremeter method

6. Example: Plate Load Tests in Venette, France

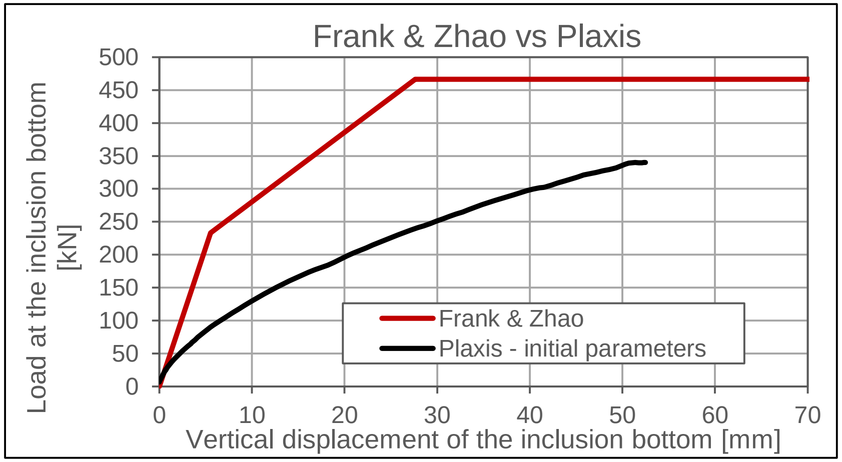
- **Load test curve with initial parameters – Comparison with Frank and Zhao's mobilization laws**



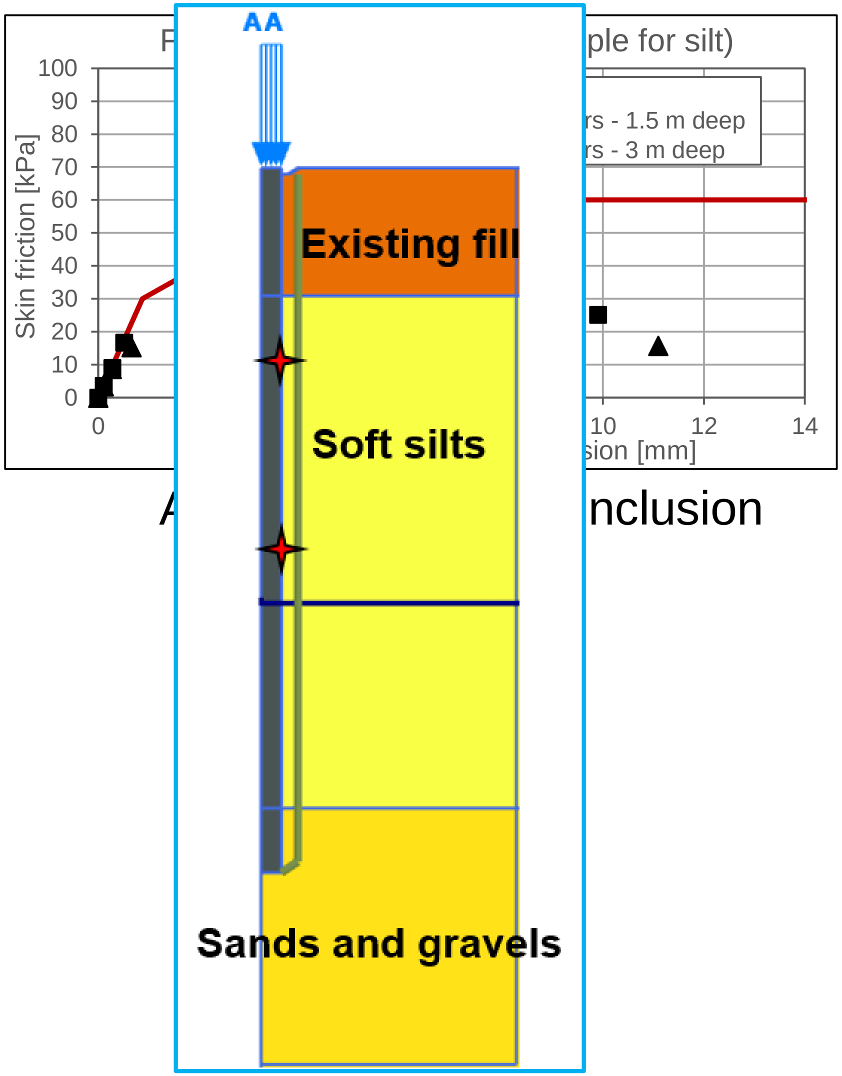
At inclusion bottom

6. Example: Plate Load Tests in Venette, France

- **Load test curve with initial parameters – Comparison with Frank and Zhao's mobilization laws**



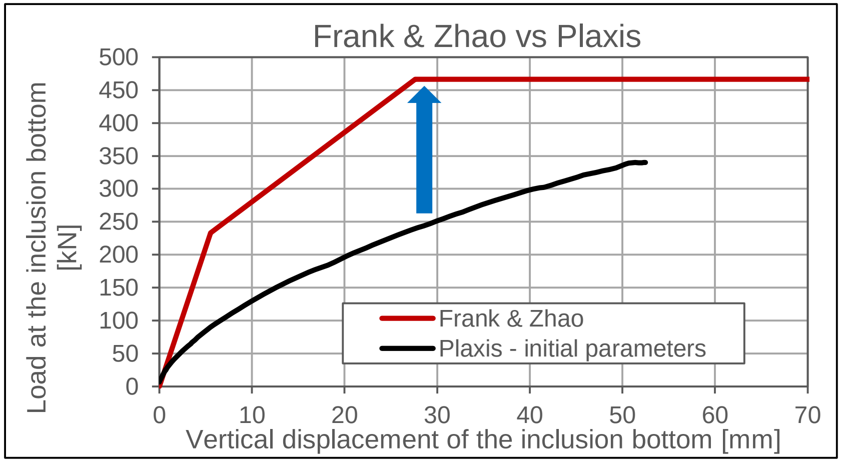
At inclusion bottom



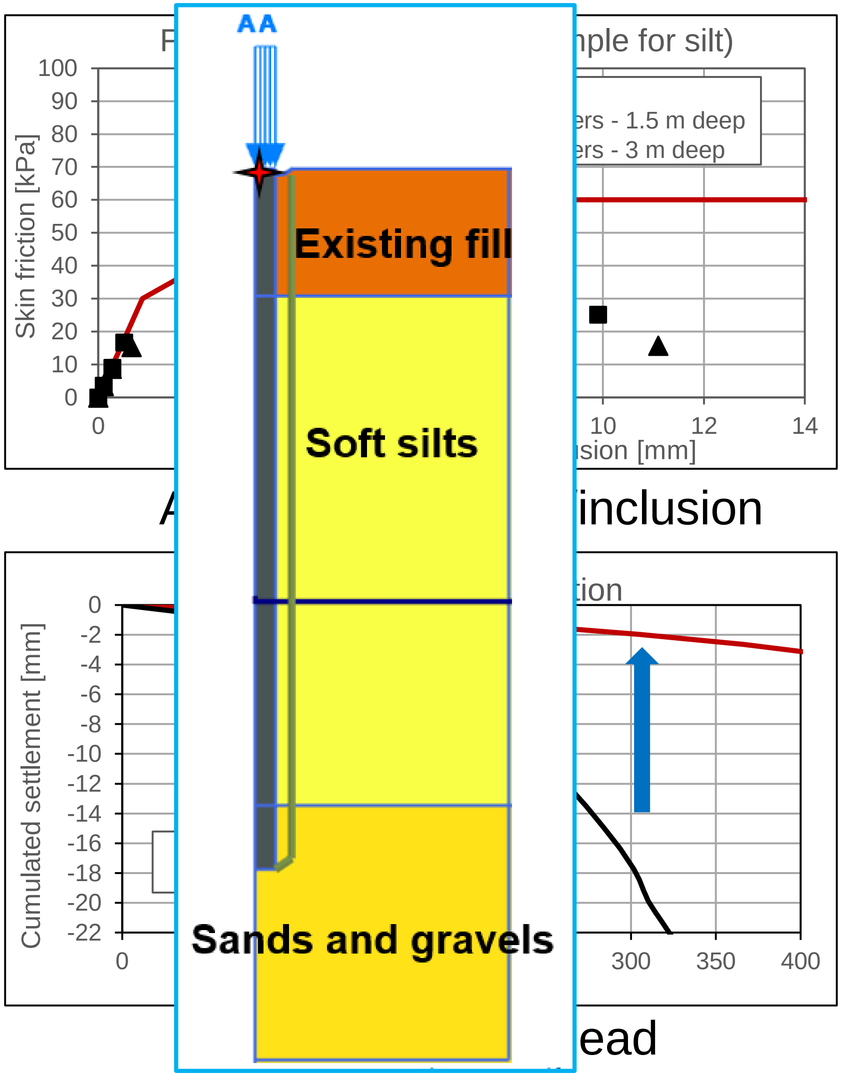
A
nclusion

6. Example: Plate Load Tests in Venette, France

- **Load test curve with initial parameters – Comparison with Frank and Zhao’s mobilization laws**



At inclusion bottom



→ adjust modelling parameters to calibrate the Plaxis curve on Frank & Zhao’s semi-empirical laws

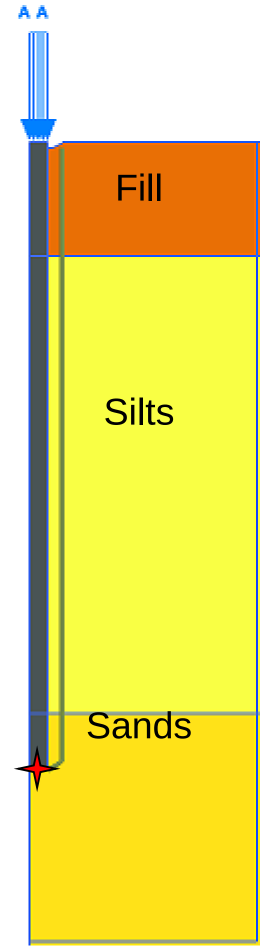
6. Example: Plate Load Tests in Venette, France

- **Calibrated parameters**
  - Skin friction

		γ	c'	φ'	E_Y	R_{inter}
		[kN/m³]	*[kPa]*	*[°]*	*[MPa]*	*[-]*
	Fill	20	**80**	**0**	30	1
	Silts	20	**60**	**0**	11	1
	Interface Sands	16.5	**170**	**0**	157.5	1

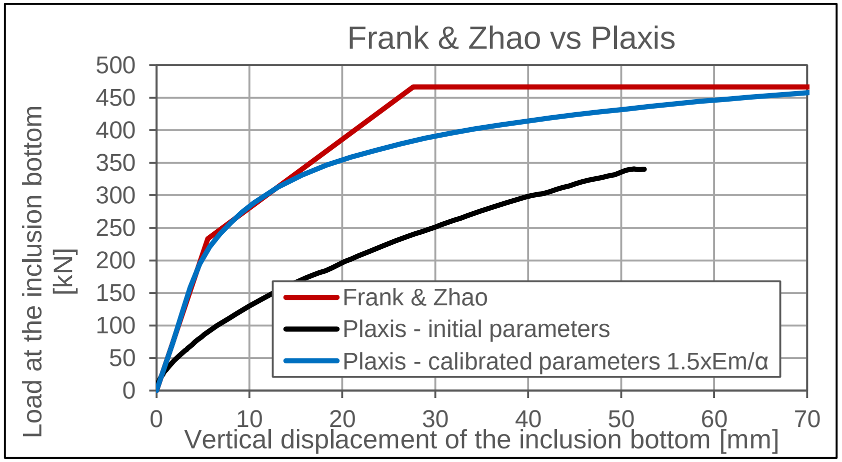
  - Inclusion bottom behaviour

		γ	c'	φ'	E_Y
		[kN/m³]	*[kPa]*	*[°]*	*[MPa]*
	Sands	16.5	**650**	**0**	**1 x E_M/α, 1.5 x E_M/α, 3 x E_M/α ?**



6. Example: Plate Load Tests in Venette, France

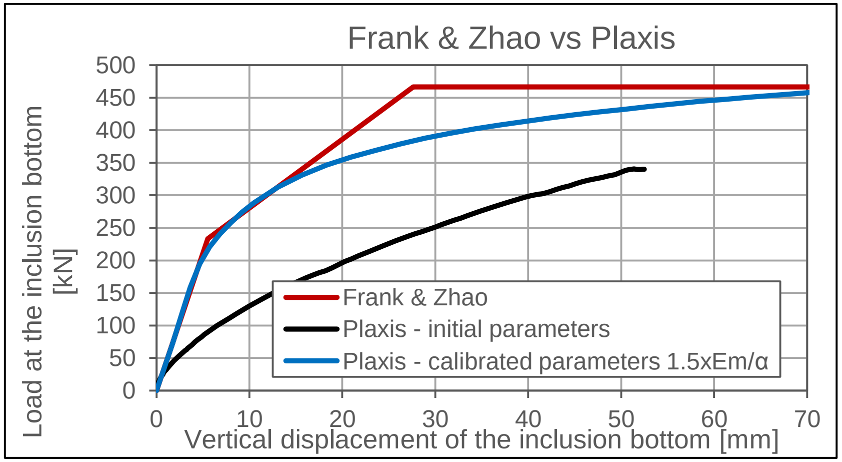
- **Load test curve with calibrated parameters – Comparison with Frank and Zhao's mobilization laws**



At inclusion bottom

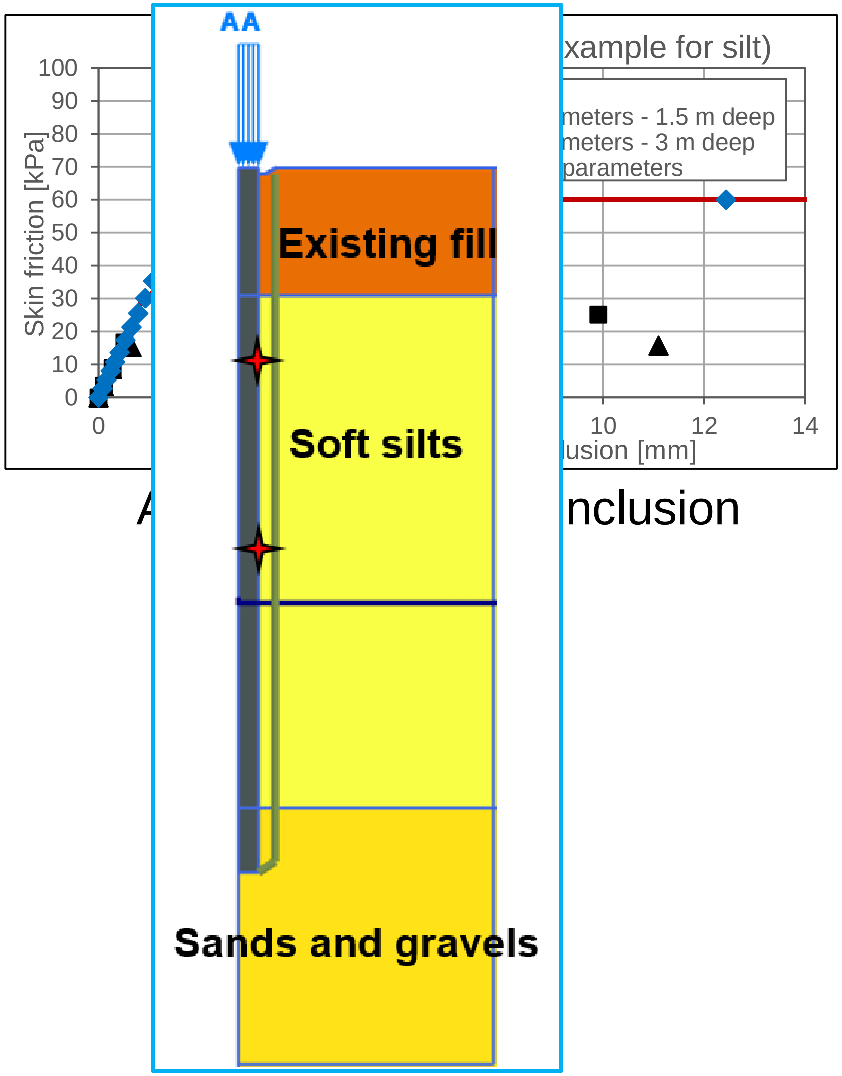
		γ	c'	φ'	E_Y
		[kN/m³]	[kPa]	[°]	[MPa]
	Sands	16.5	**650**	**0**	**= 1.5 x E_M/α = 157.5**

- **Load test curve with calibrated parameters – Comparison with Frank and Zhao's mobilization laws**



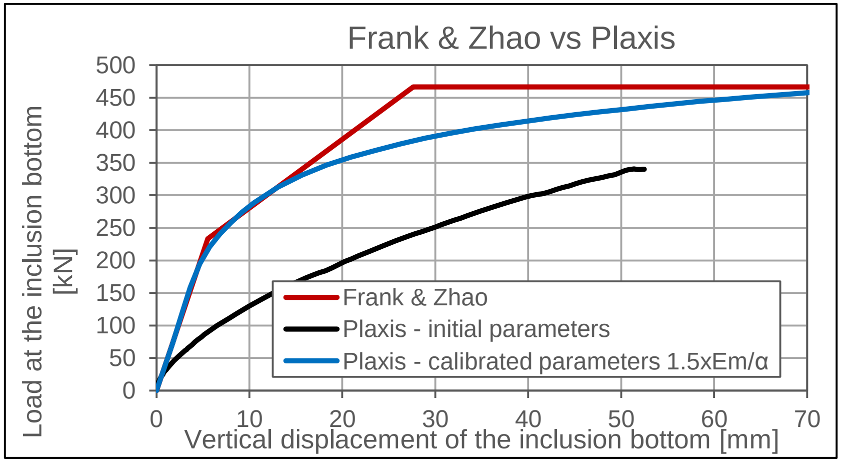
At inclusion bottom

	γ	c'	φ'	E_Y
	[kN/m³]	[kPa]	[°]	[MPa]
Sands	16.5	650	0	= 1.5 x E_M/α = 157.5



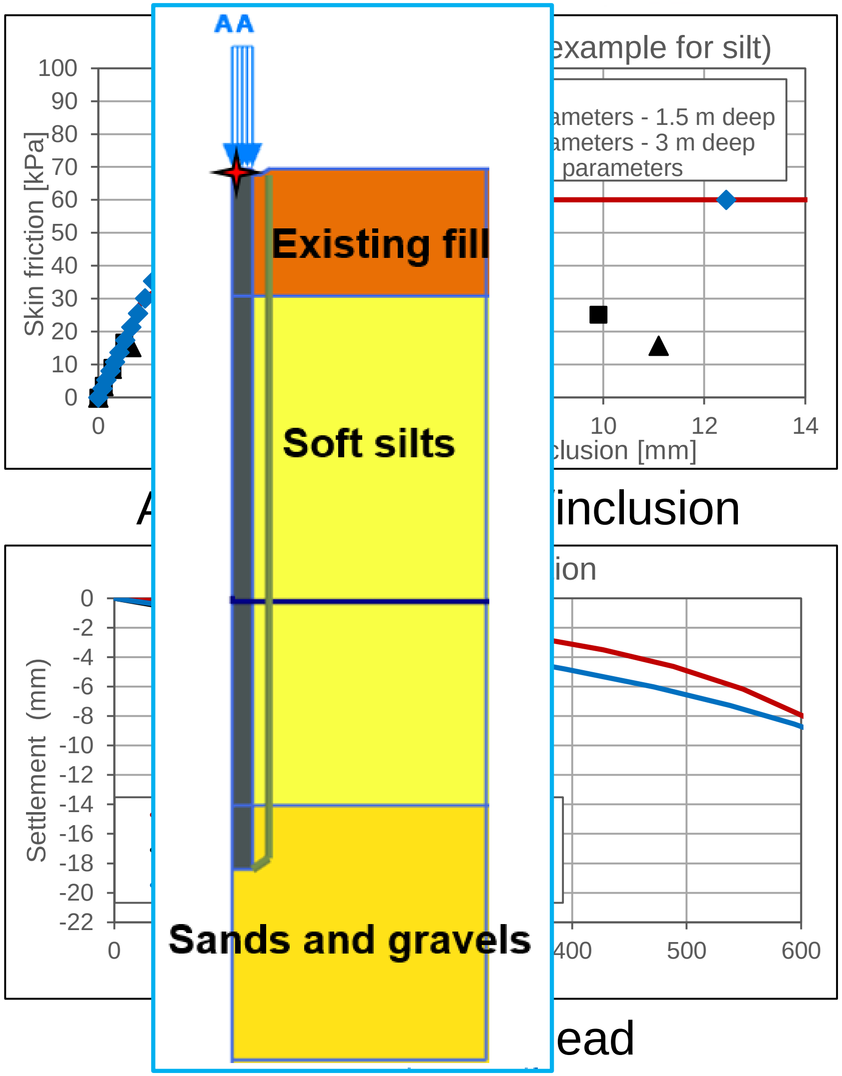
6. Example: Plate Load Tests in Venette, France

- **Load test curve with calibrated parameters – Comparison with Frank and Zhao's mobilization laws**



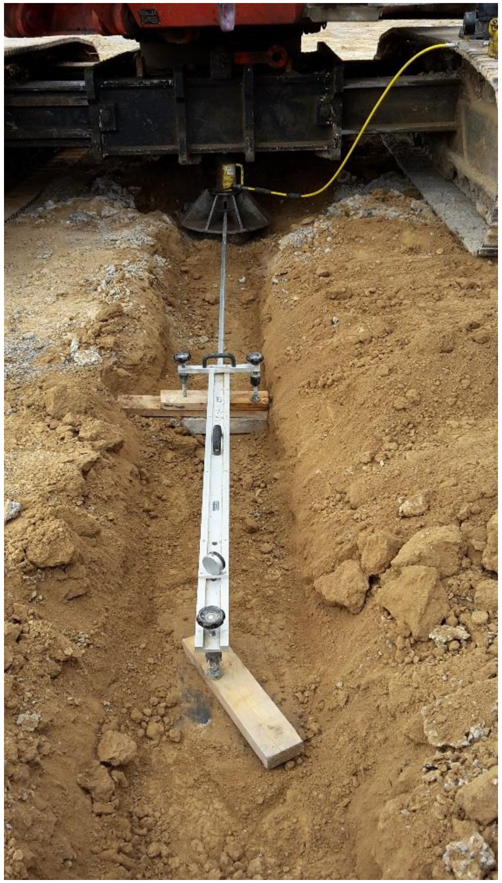
At inclusion bottom

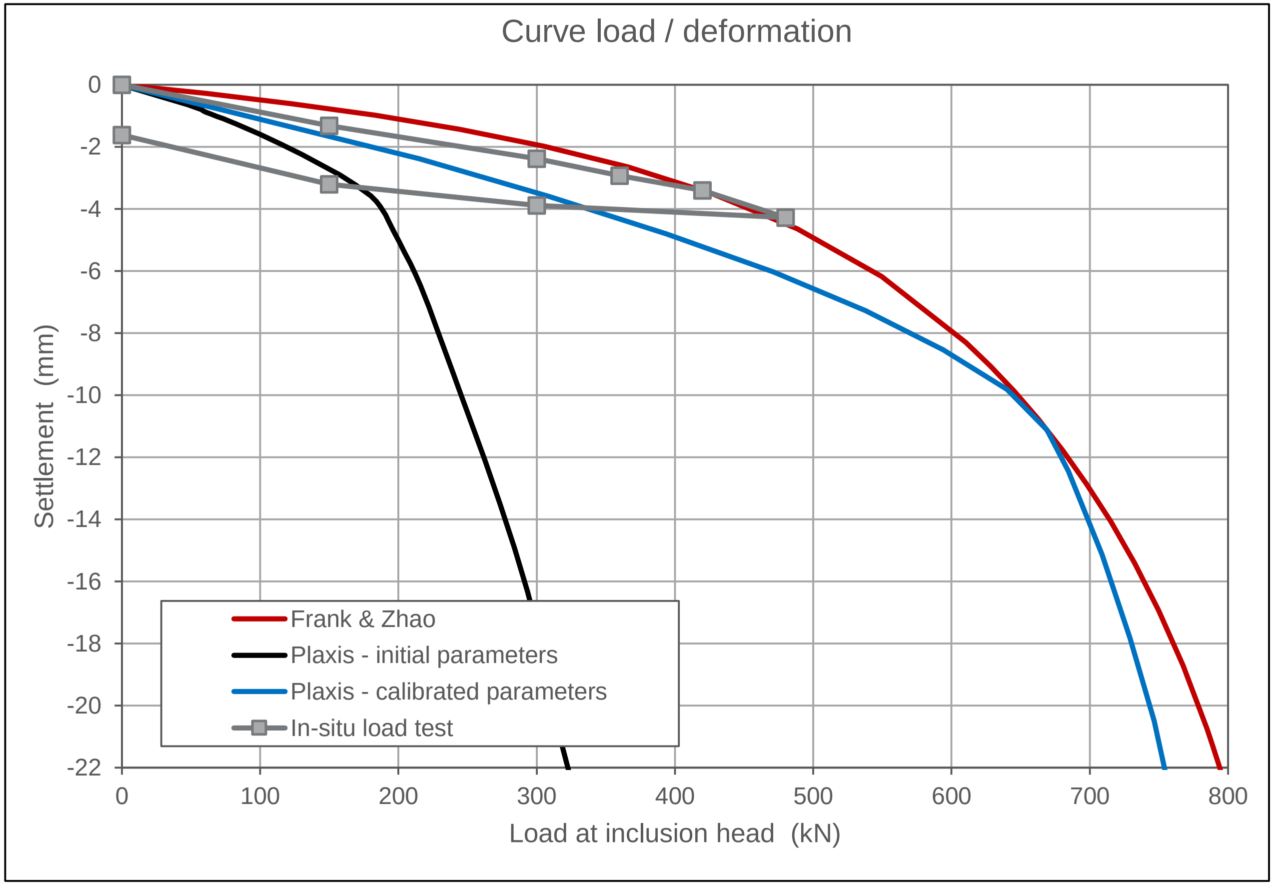
		γ	c'	φ'	E_Y
		[kN/m³]	[kPa]	[°]	[MPa]
	Sands	16.5	650	0	$= 1.5 \times E_M/\alpha = 157.5$



6. Example: Plate Load Tests in Venette, France

- **Load test curve with calibrated parameters – Comparison with in-situ load test**





7. Conclusion

- **Classical determination of the FE input parameters is often very conservative**
- **The calibration of the input parameters on the empirical curves from Frank & Zhao allows to better simulate the rigid inclusion behaviour**
- **The Frank & Zhao curves require the use of the pressuremeter test parameters E_m et p_l**
- **Three modelling parameters need to be calibrated:**
  - Effective cohesion
  - Effective friction angle
  - Young's modulus

Thank you for your attention