UNIVERSITEIT GENT

Feasibility study on bamboo foundation mats for rubble mound breakwaters on soft soil layers

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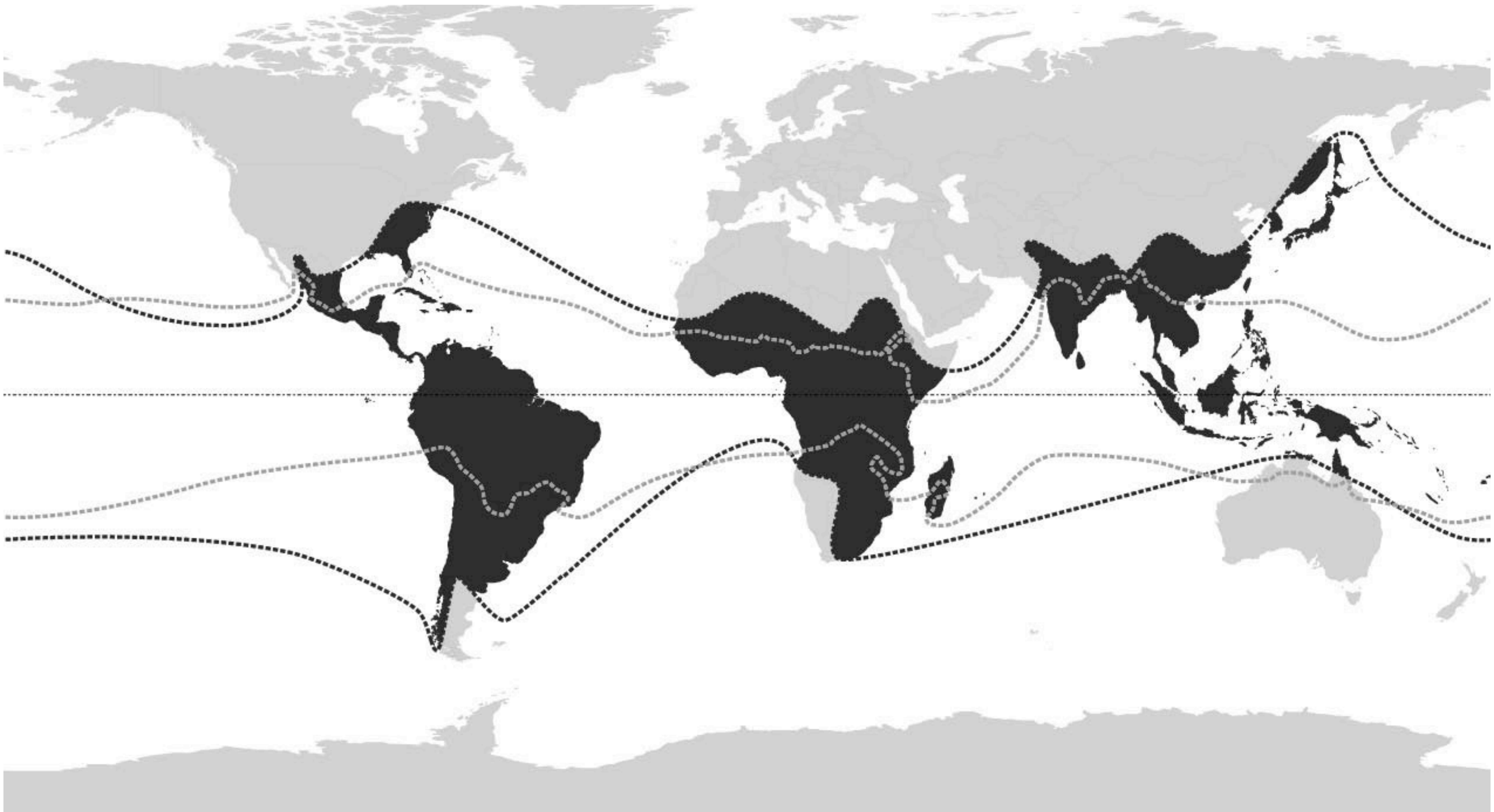
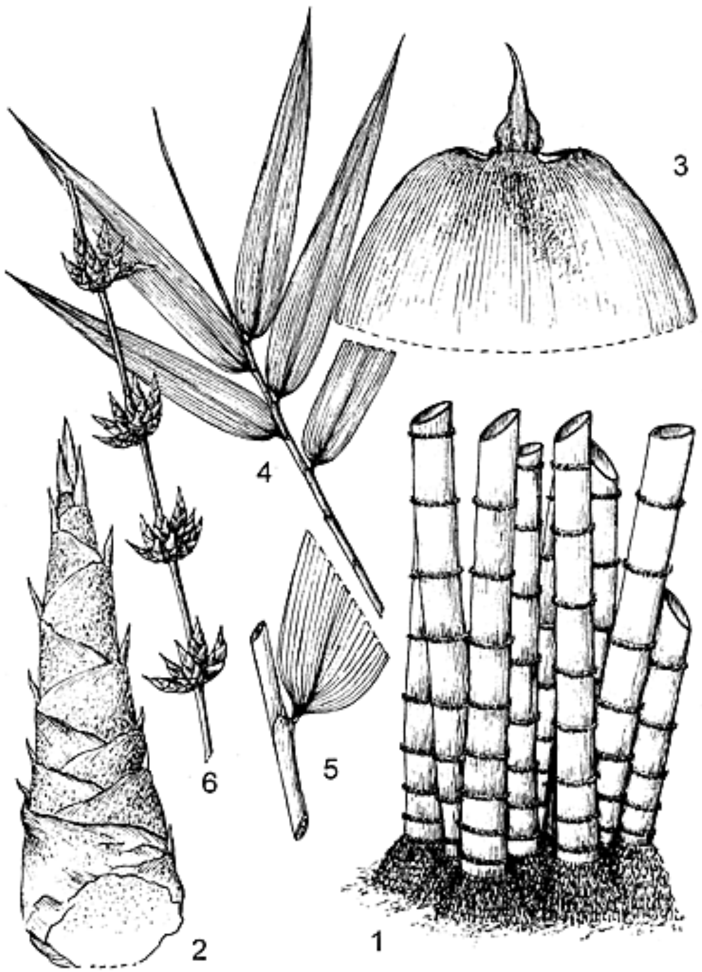
Supervisor: Dr. Ramiro Verastegui Flores

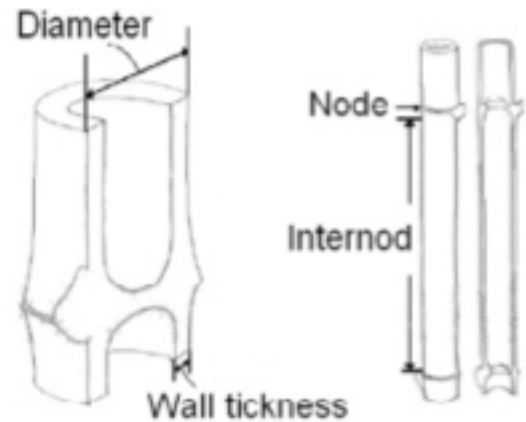
Black line: Global natural bamboo habitat
Grey line: World’s tropical zone



Dendrocalamus barbatus

- Local species growing near the construction site





Content

Why bamboo

Strength properties of bamboo

Pull-out properties of the bamboo mat

Safety factor of a breakwater
reinforced with a bamboo mat

Design of a bamboo mat

Conclusion

Content

Strength properties of the dendrocalamus barbatus

Symbol	Steel	Tensar SS40	Bamboo	Unit
$\sigma_{t,0}$	200-400	-	>85.4	N/mm^2
$\sigma_{c,0}$	200-400	-	>25	N/mm^2
$\sigma_{c,90}$	200-400	-	>2.05	N/mm^2

Symbol	Tensar SS40	Bamboo	Unit
$T_{t,0}$	40	>865.83	N/mm^2
$T_{c,0}$	40	>123.69	N/mm^2

Pull-out proportions of the bamboo mat

- Theoretical approach
- Fill system
- Reinforcement materials
- Backfill material
- Pull-out test results
- Numerical approach (Plaxis)

Theoretical approach

- $F_{tot} = F_f + F_b$
- F_f = Friction resistance

$$F_f = A_s * \sigma_a' * \tan\delta$$

- F_b = Passive bearing resistance

$$F_b = N * W * d(y) * \sigma_{bm} * (1-DI)$$

- σ_{bm} = to determine:
  - » Prandl and Buisman
  - » Jewell et al
  - » Peterson and Anderson
  - » Experimental
  - » Numerical

Theoretical approach

- $F_{tot} = F_f + F_{be}$
- F_f = Friction resistance

$$F_f = A_s * \sigma_a' * \tan\delta$$

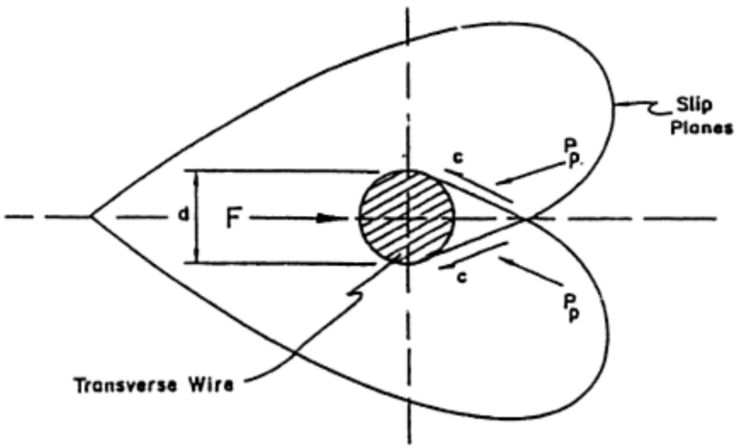
- F_b = Passive bearing resistance

Interference of the transversal members

$$F_b = N * W * d(y) * \sigma_{bm} * (1\text{-}DI)$$

- σ_{bm} = to determine:
  - » Prandl and Buisman
  - » Jewell et al
  - » Peterson and Anderson
  - » Experimental
  - » Numerical

Peterson and Anderson



$N_q = e^{(\pi \tan \phi')} \tan^2 (45 + \phi'/2)$

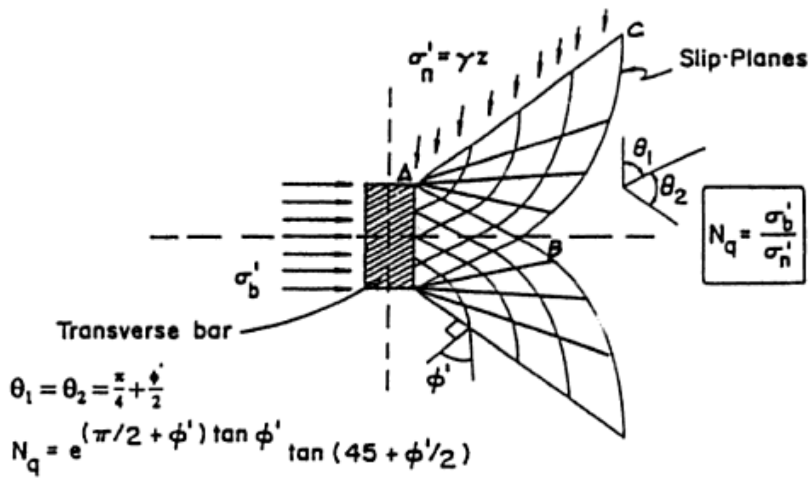
$$N_q = \frac{\sigma'_b}{\sigma'_v}$$

$$\sigma'_b = N_q \times \sigma'_v = \exp\left[\pi \times \tan\phi'\right] \times \left[\tan^2\left(\frac{\pi}{4} + \frac{\phi'}{2}\right)\right] \times \sigma'_v$$

where:

N_q Bearing capacity factors
σ'_b Bearing capacity resistance
σ'_v Effective vertical stress
ϕ' effective internal friction angle of the soil

Jewell et al



$$N_q = \frac{\sigma'_b}{\sigma'_n}$$

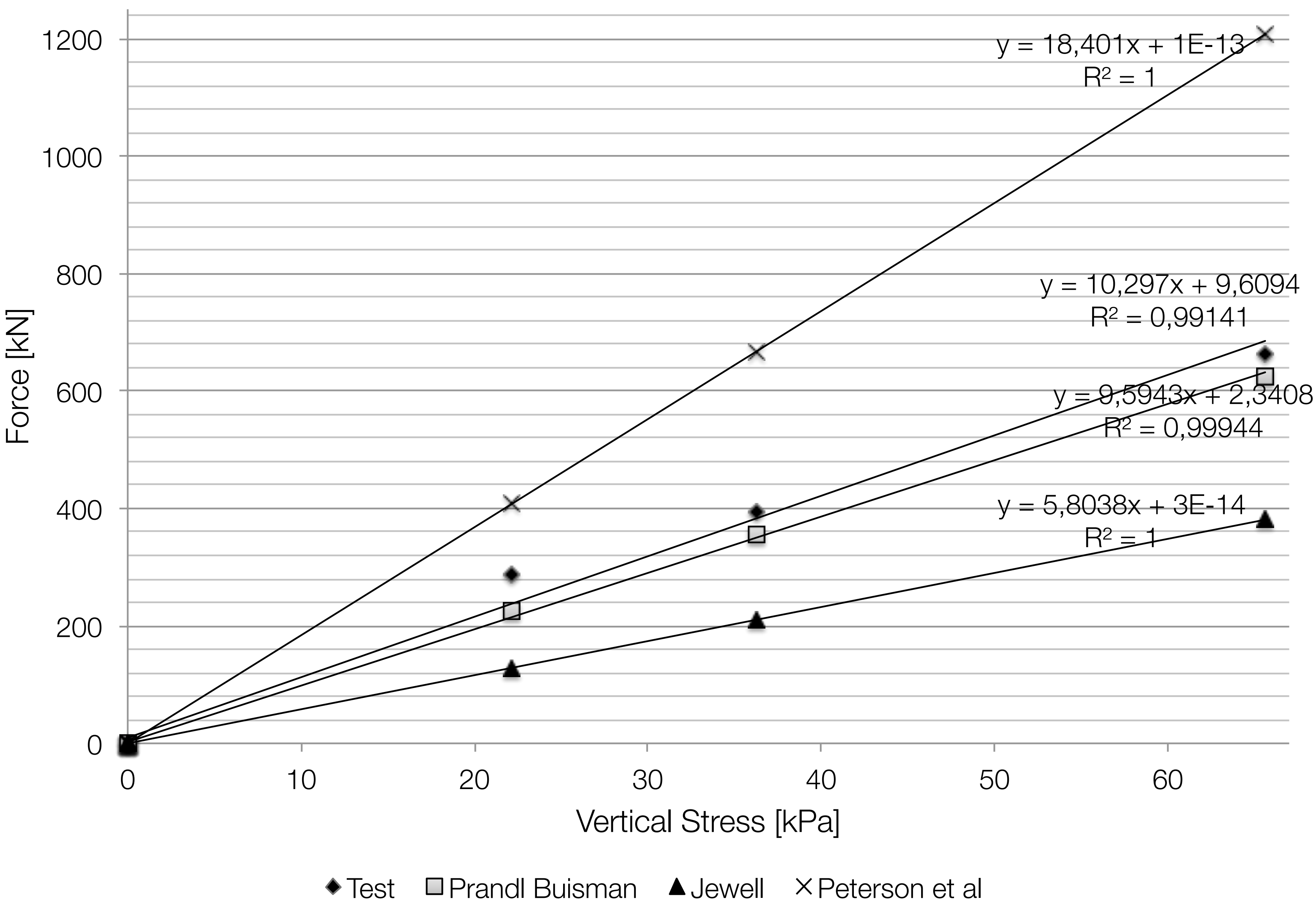
$$\frac{\sigma'_b}{\sigma'_v} = \exp\left[\left(\frac{\pi}{2} + \phi'\right) \times \tan\phi'\right] \times \left[\tan\left(\frac{\pi}{4} + \frac{\phi'}{2}\right)\right]$$

Prandl and Buisman

$$P_r = V_b \times p_b + V_c \times c + V_g \times \gamma_k \times b$$

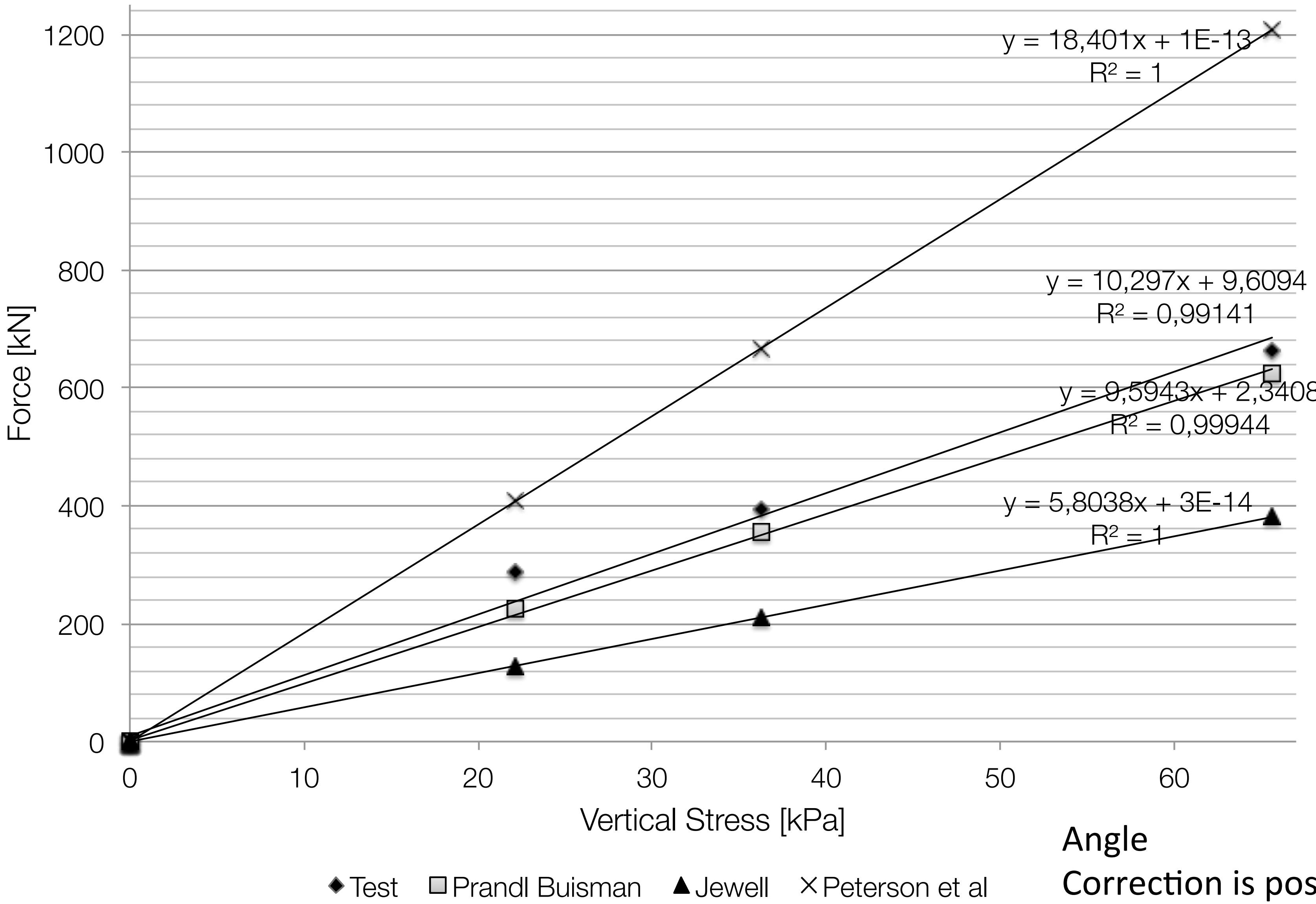
P_r	Critical fraction surface
$B_b \times p_b$	Effect of the side load p_b next to the foundation on the foundation level
$V_c \times c$	Cohesion along the slip plane
$V_g \times \gamma_k \times B$	Weight of the soil mass under the foundation
γ_k	Density of the soil
B_l	Width of the loaded strip

Results



y = 18,401x + 1E-13
R² = 1
y = 10,297x + 9,6094
R² = 0,99141
y = 9,5943x + 2,3408
R² = 0,99944
y = 5,8038x + 3E-14
R² = 1
1200
1000
800
600
400
200
0
Force [kN]
0
10
20
30
40
50
60
Vertical Stress [kPa]
Test
Prandl Buisman
Jewell
Peterson et al

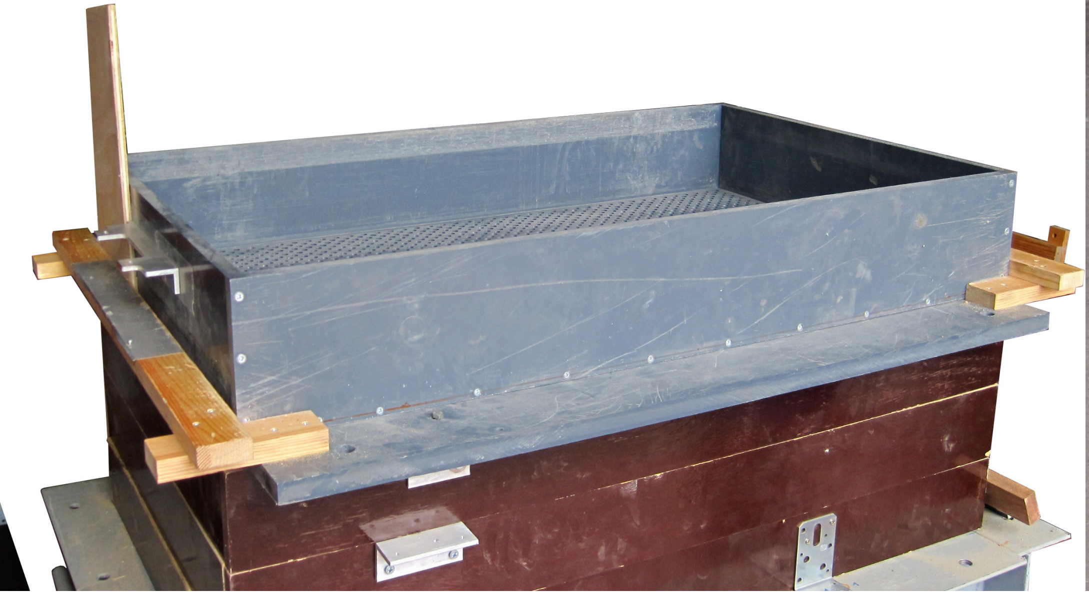
Results

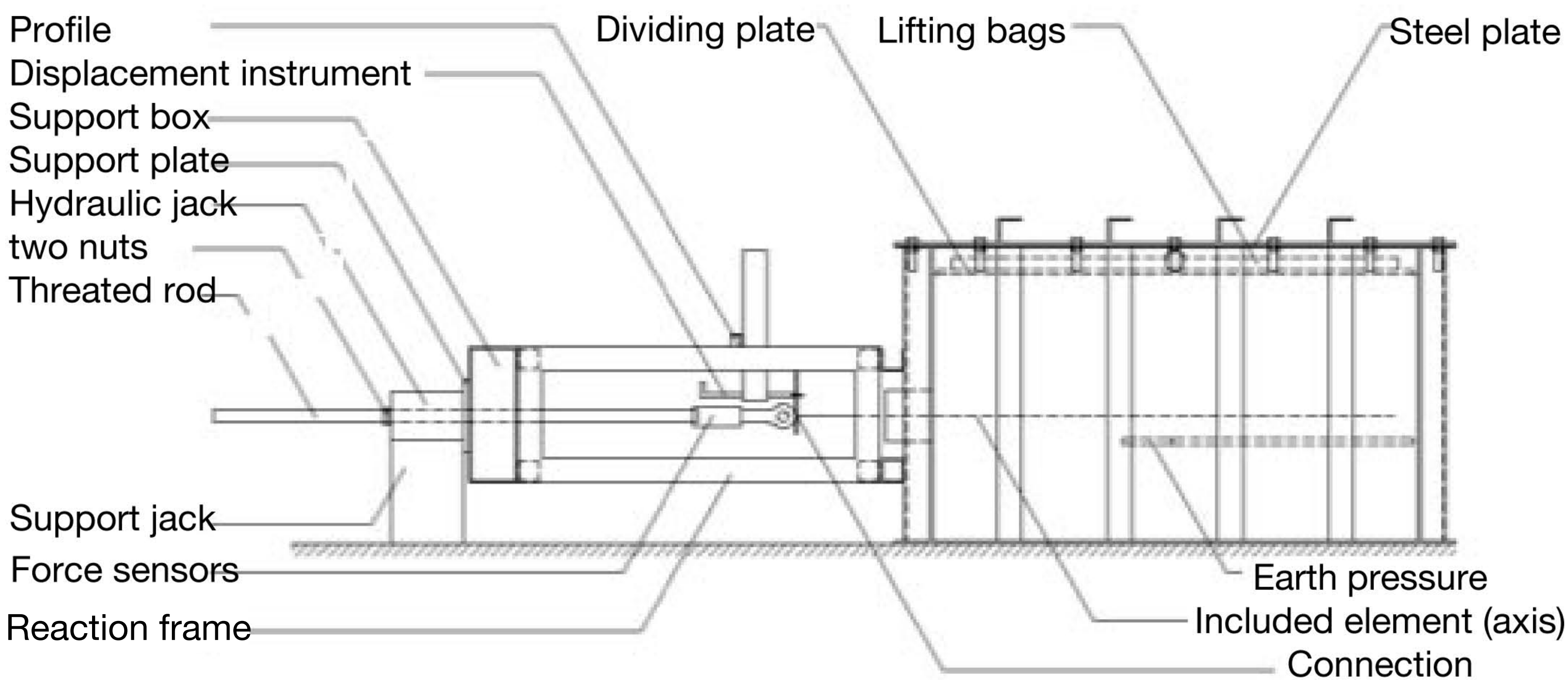


Angle
Correction is possible?

Fill system

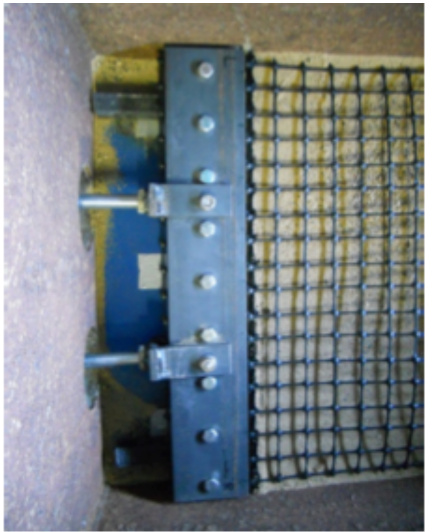
Fill system

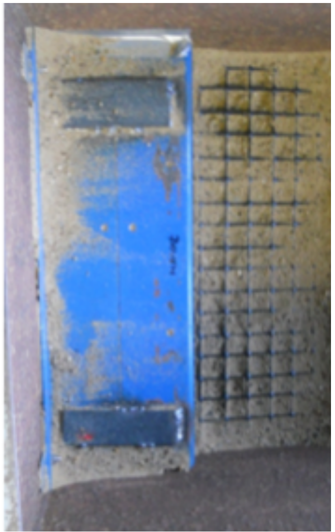




Profile
Displacement instrument
Support box
Support plate
Hydraulic jack
two nuts
Threated rod
Support jack
Force sensors
Reaction frame
Dividing plate
Lifting bags
Steel plate
Earth pressure
Included element (axis)
Connection

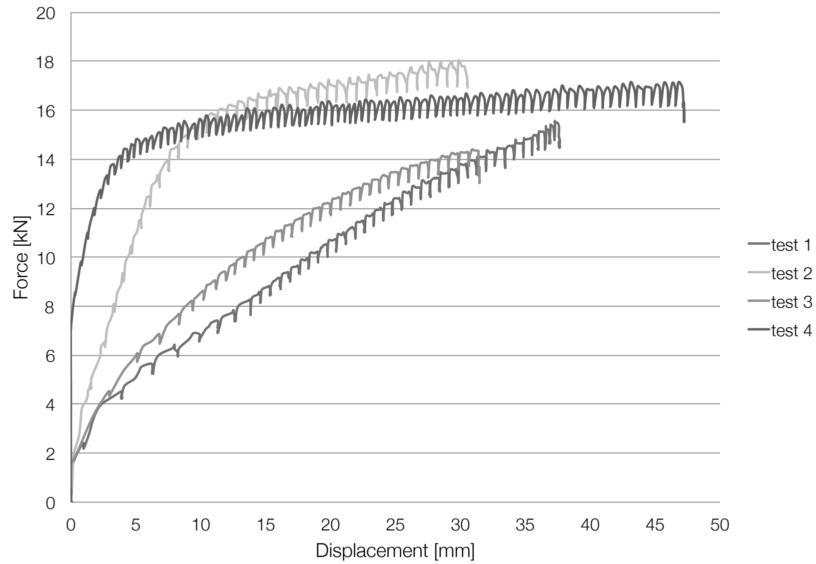
Reinforcement materials

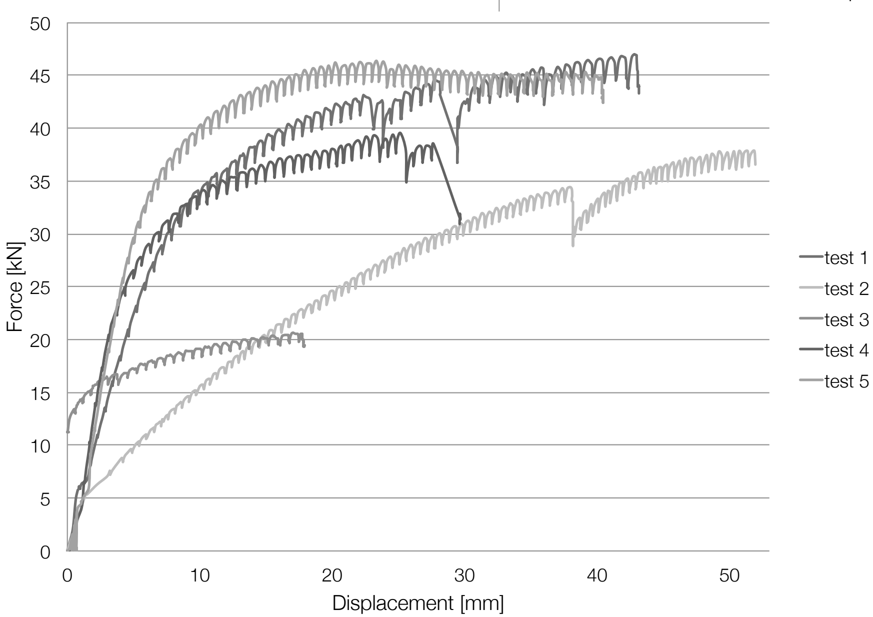


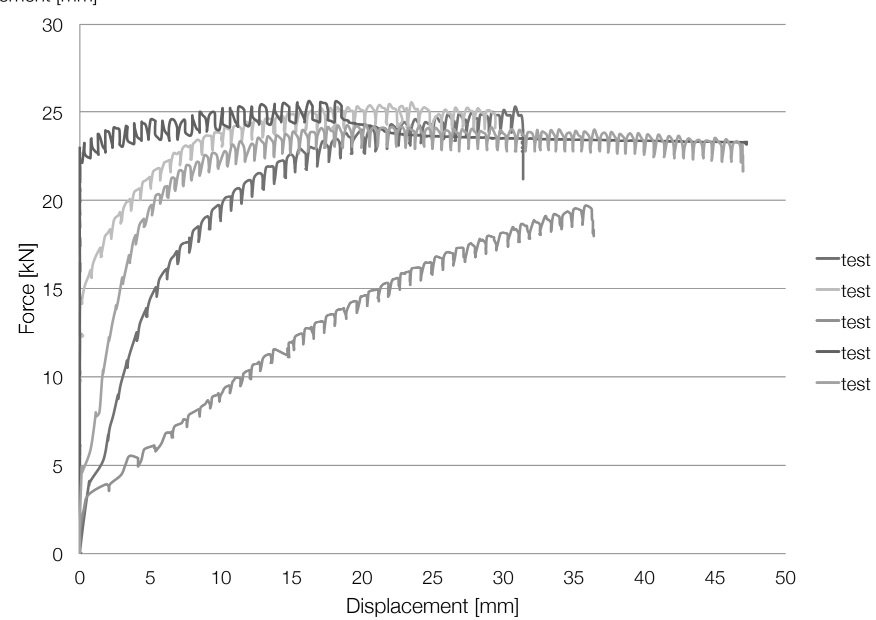


Not compacted sand

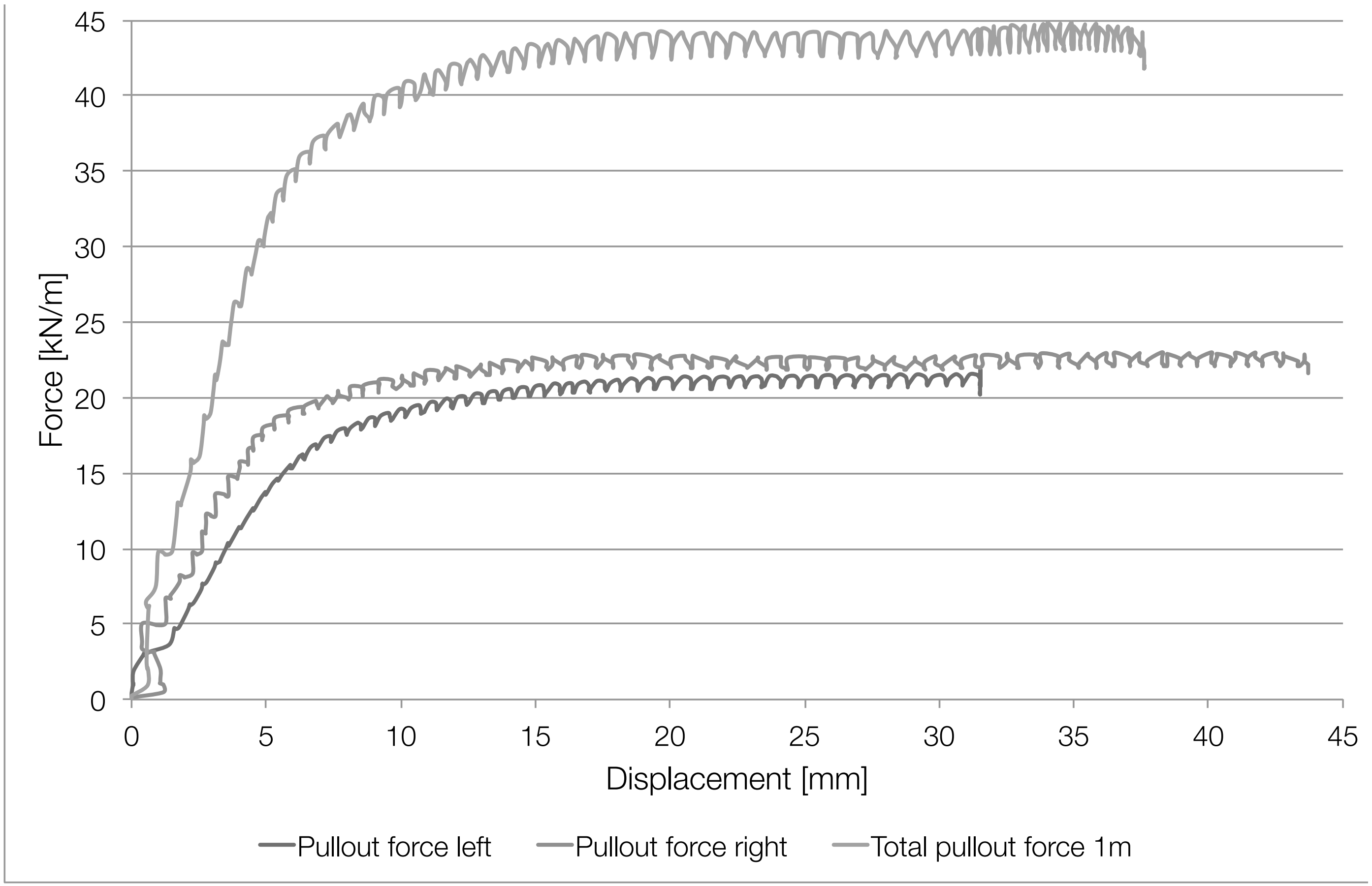
Bamboo mat
5.6cm diameter
21kPa
35kPa
67kPa





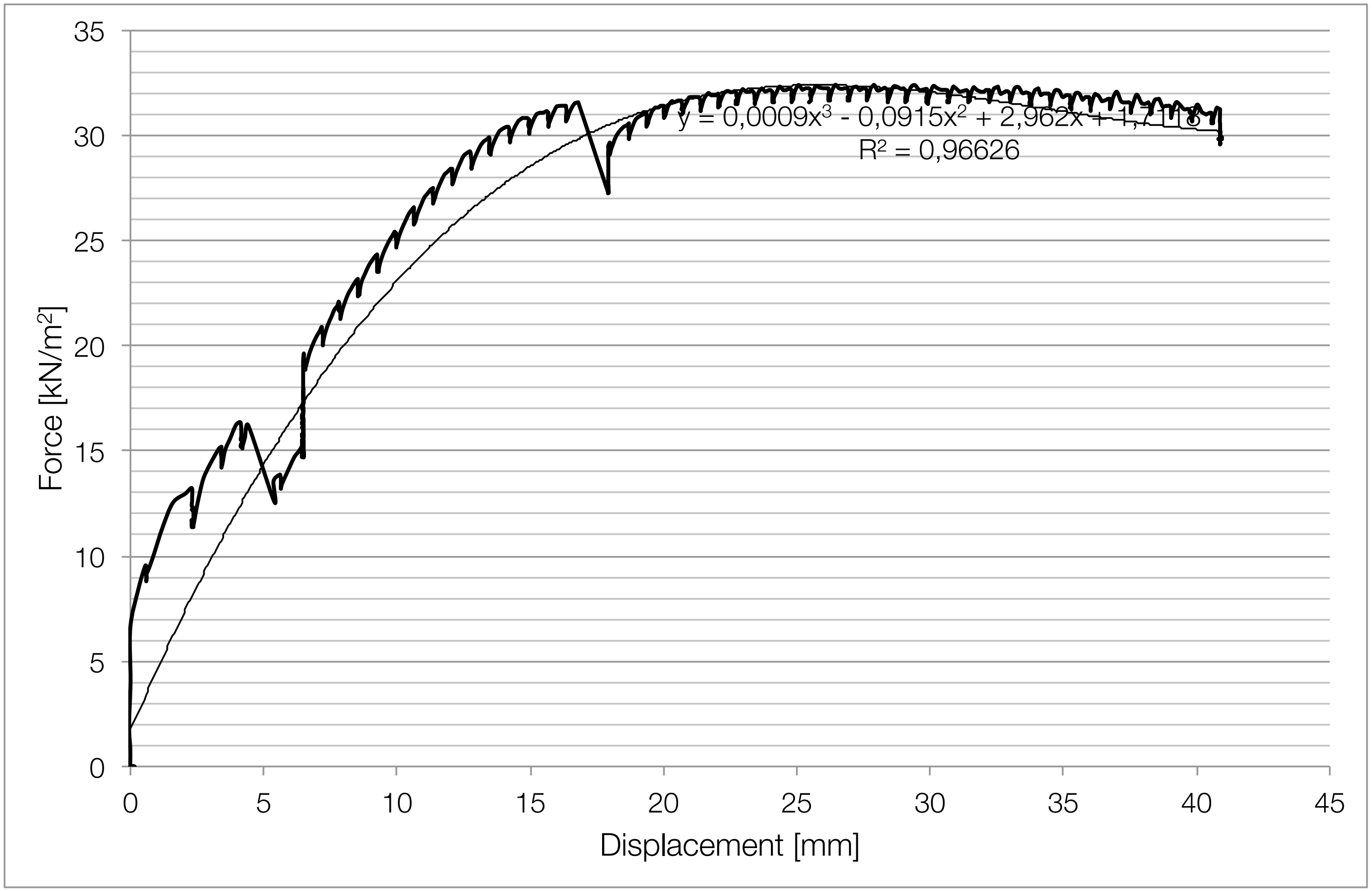


Compacted sand



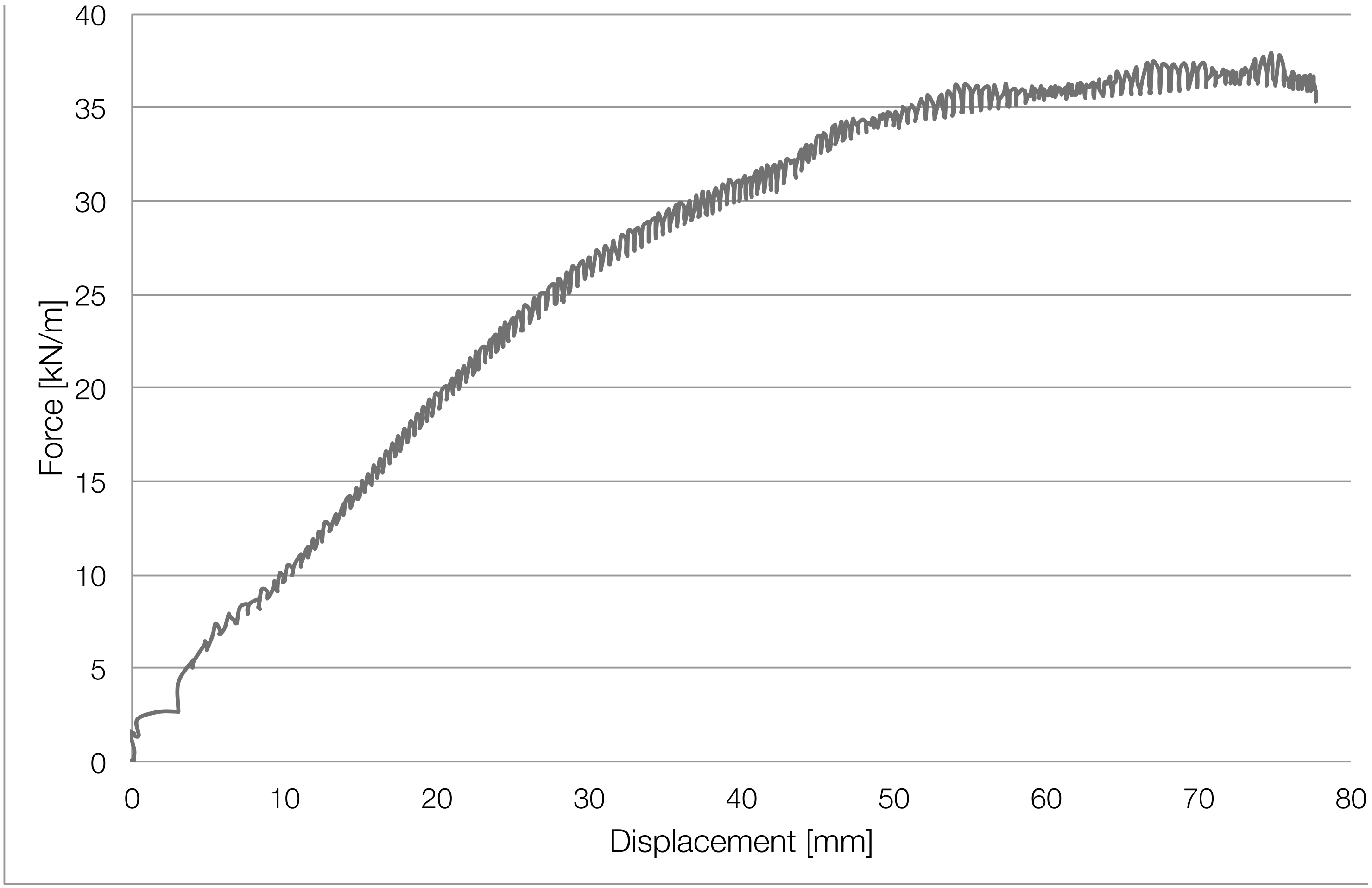
Transversal bamboo member
6cm diameter with 57kPa

Compacted sand



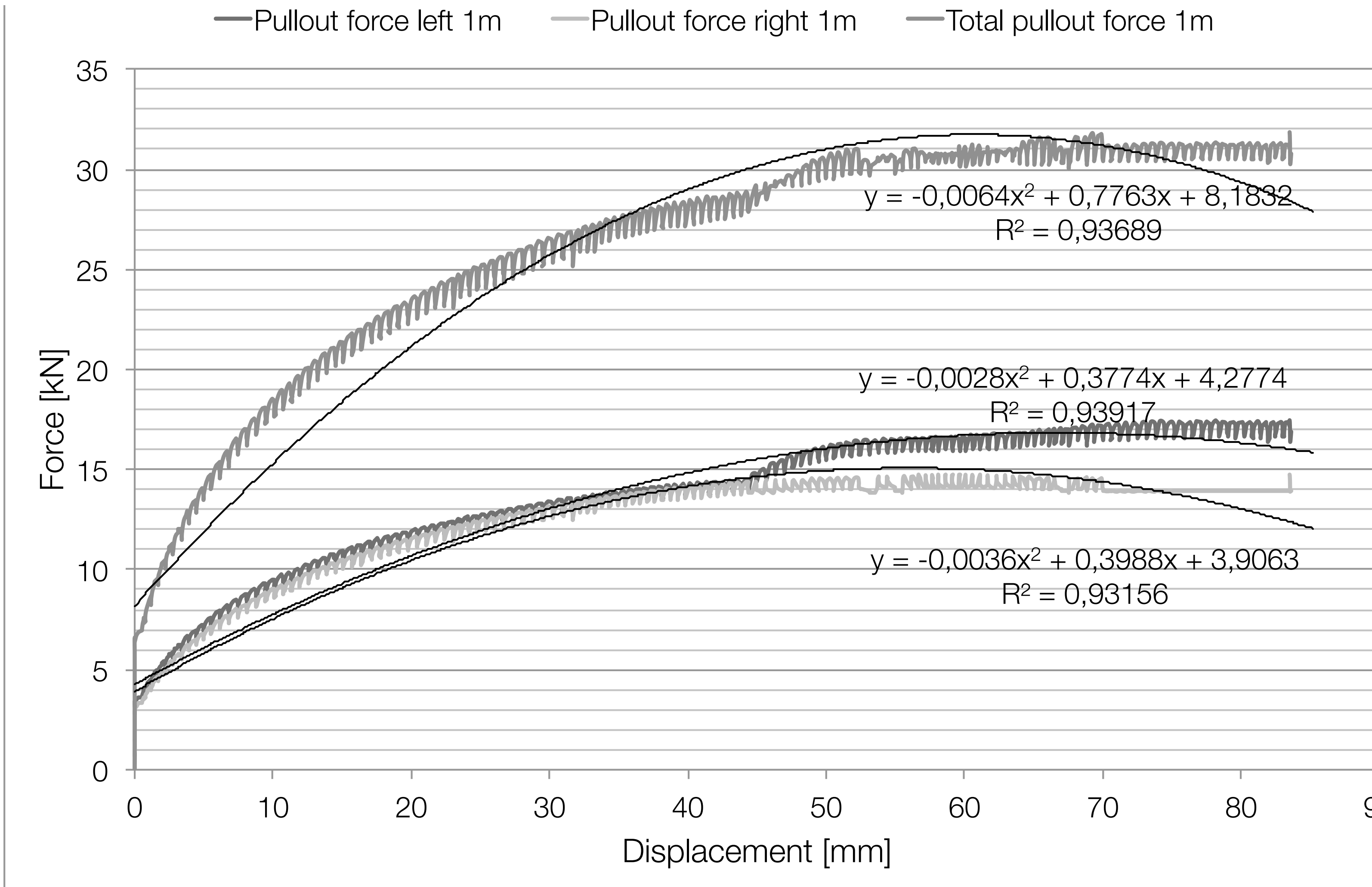
Geogrid with 51kPa

Wet Sand



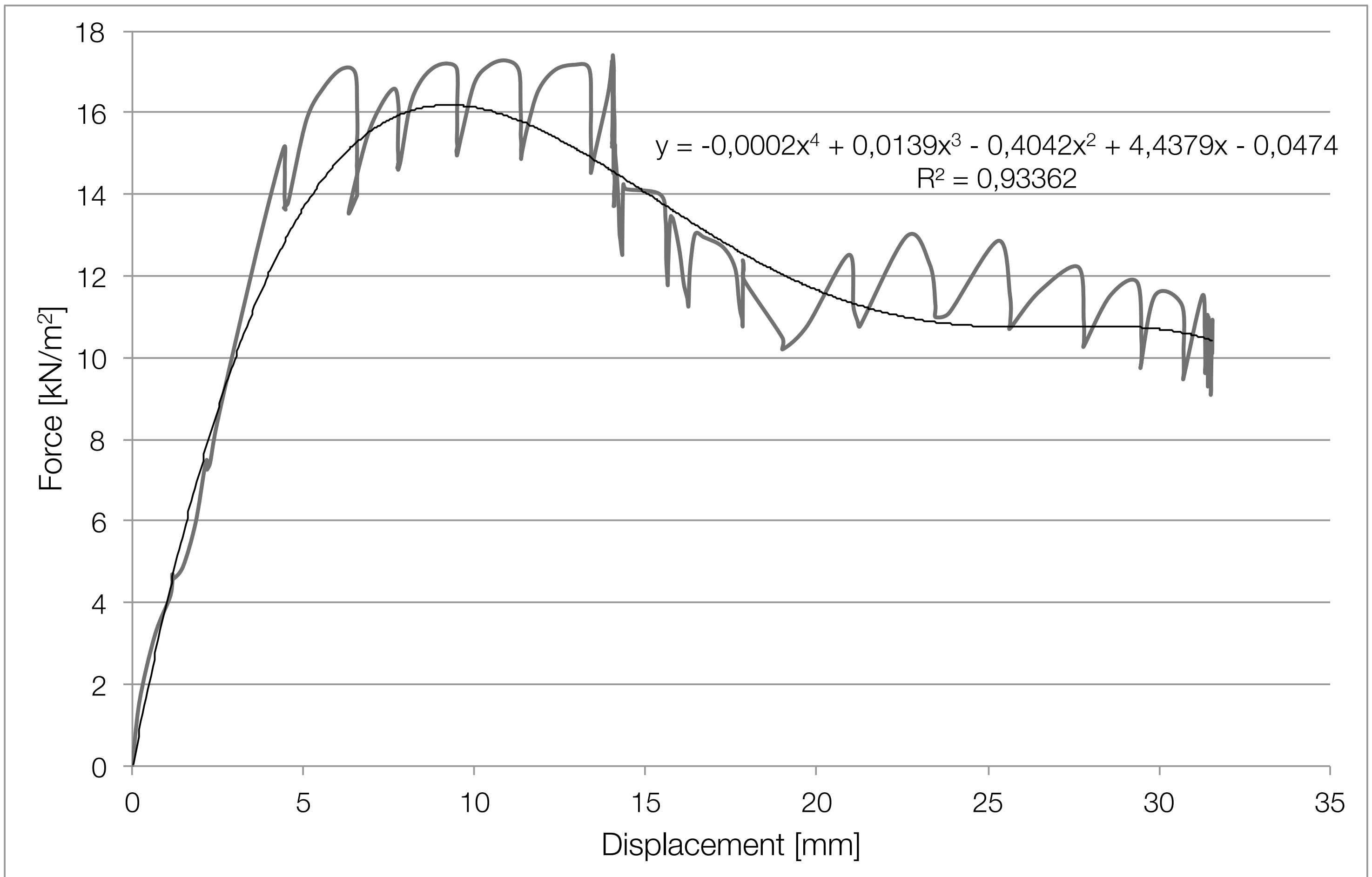
Tranversal bamboo member
5cm diameter 56kPa

Clay layer: Koalin



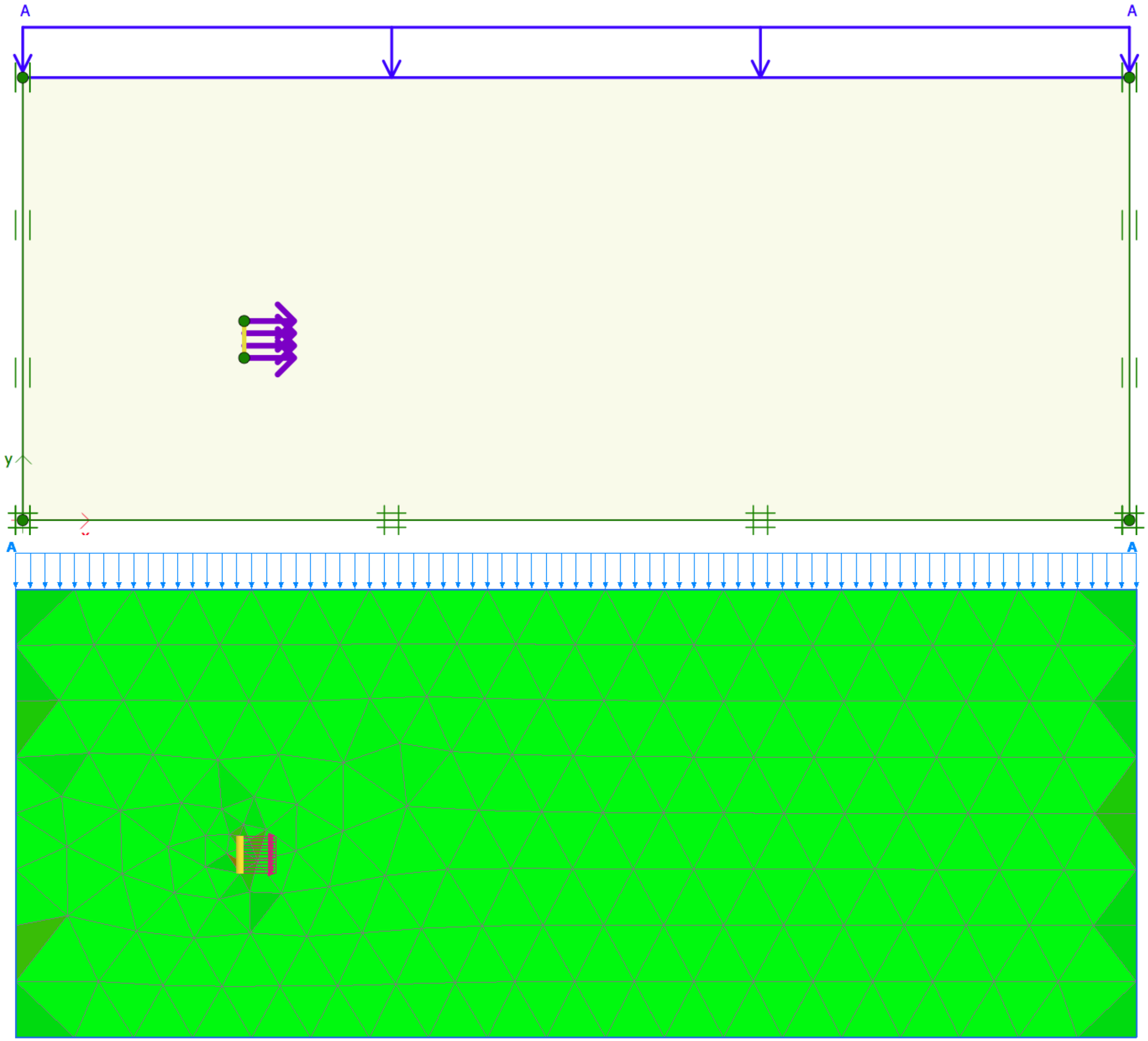
Bamboo mat 57 kPa
5.6cm diameter

Clay layer: Koalin

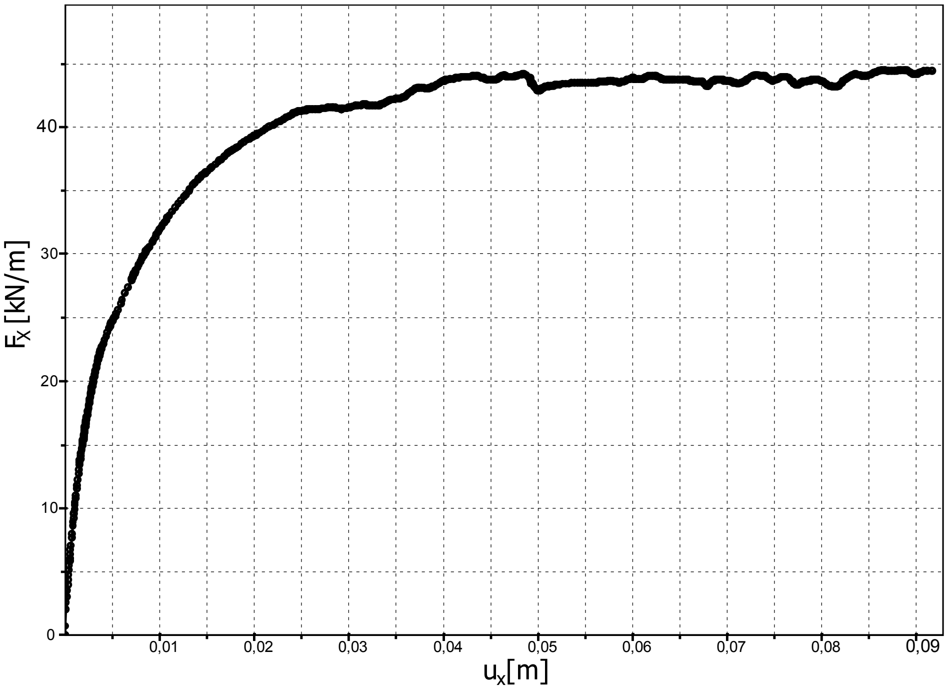


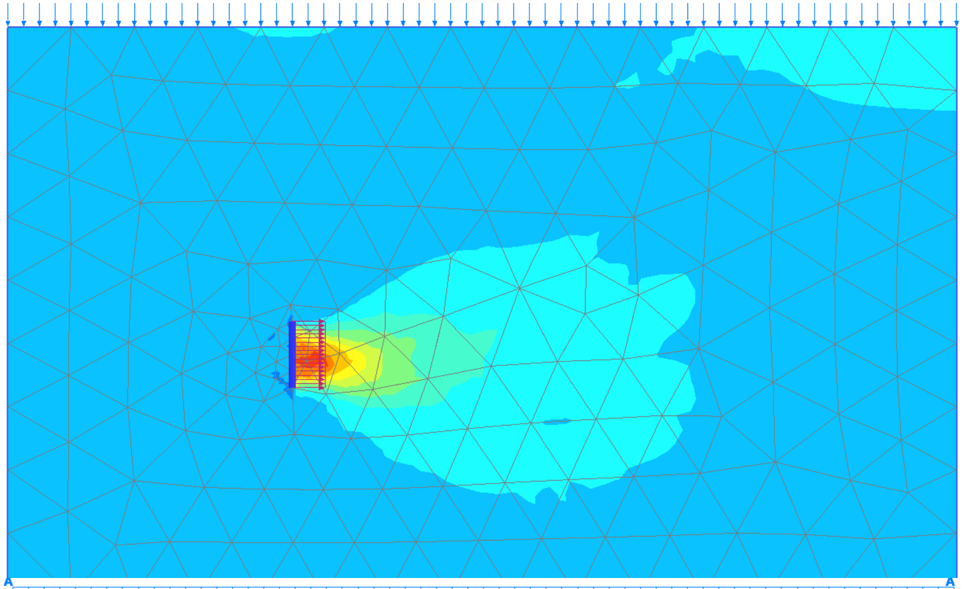
Geogrid 55kPa

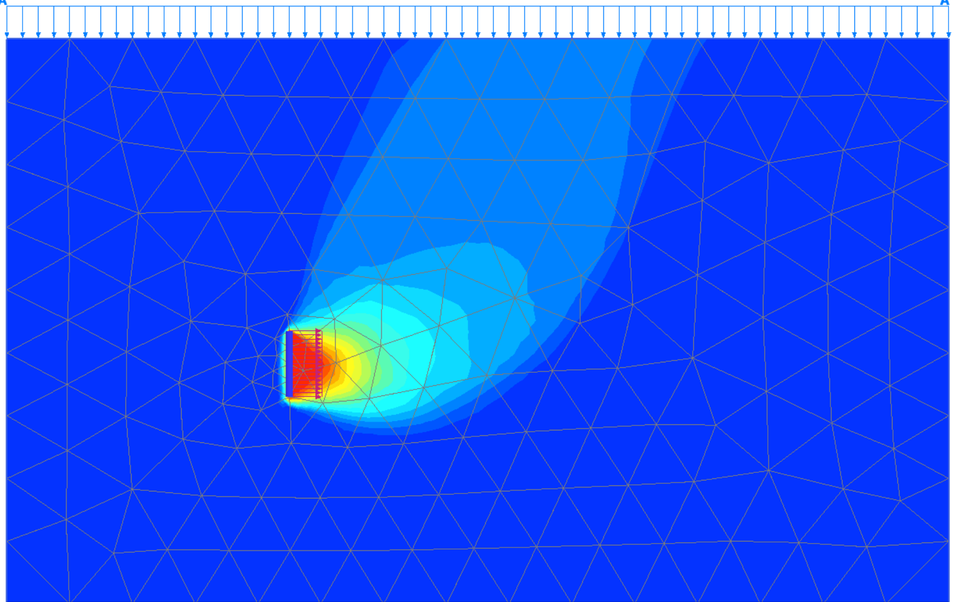
Plaxis



Plaxis







Compare of the results?

- Because of the different pressure for each test it is recommended to calculate the friction/ bearing resistance angle of the inclusions in stead of the force:

$$\phi_r = \arctan \frac{F}{F_n}$$

Results

Material	Passive bearing angle ϕ_b [°] exp.	num.	Prandl	Jewell	Pet.
	NOT COMPACTED SAND				
Bamboo mat	31.5	34.4	29.1	18.2	46.1
	COMPACTED SAND				
Bamboo mat	42.0	-	33.6	21.9	52.0
Geogrid	29.1	-	-	-	-
	COMPACTED WET SAND				
Bamboo mat	27.8	-	38.1	24.8	58.7
	CLAY LINER				
Bamboo mat	28.5	15.9	25.1	16.2	40.6
Geogrid	23	-	-	-	-

Conclusion

- Tensile resistance is better for a bamboo mat than the Tensar SS40 $40kN/m^2 << 800kN/m^2$
- Pull-out resistance is better for a Bamboo mat than the Tensar SS40
- SF is higher for the Bamboo mat than the Tensar SS40
- But durability analyses are required and a good design has to be made and checked with the real situation
- Bamboo can not resist Shear forces

Questions?