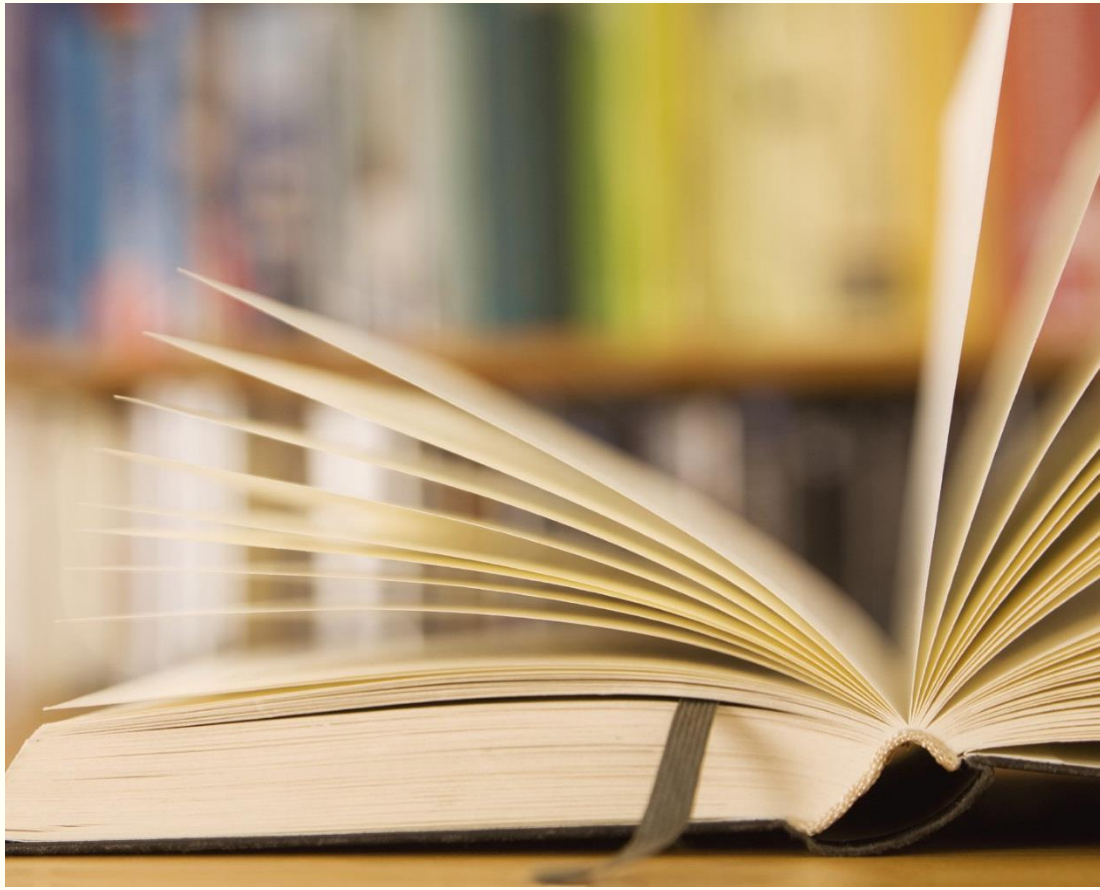
SOIL IMPROVEMENT PROJECT

Soil improvement with Stone Columns : Stone modelling

(Presenter: Afshin Zaheri, Ph.D. student)



Soil Improvement with Stone Columns

Stone Columns

- The Bearing Capacity
- Final Settlement
- Liquefaction Potential
- Degree of Consolidation
- The stability of embankments

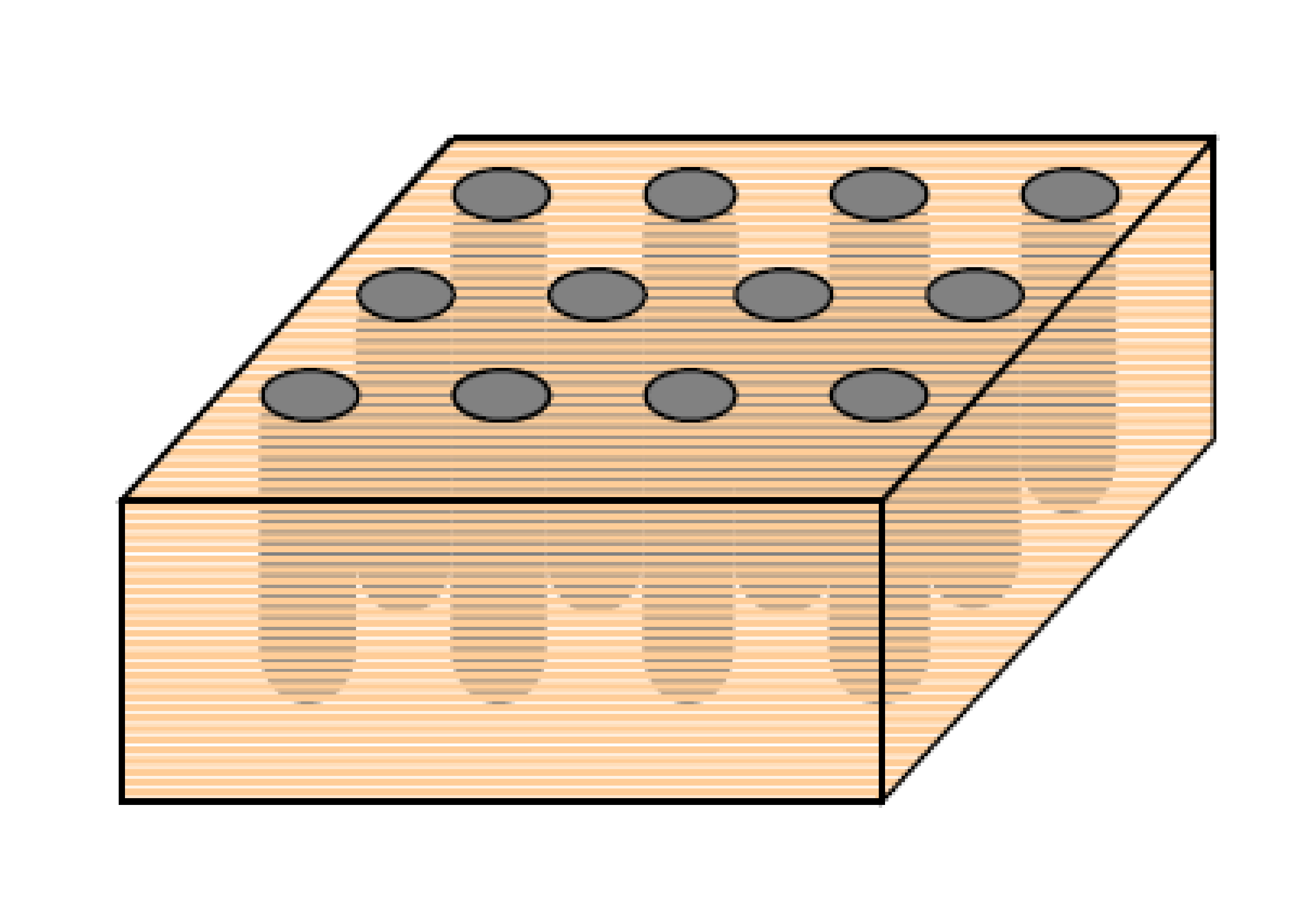
Title and Content Layout

- Stone Columns Modelling
- Verification (Numerical Modelling Plaxis 2D)
- Physical Modelling (3D Modelling)

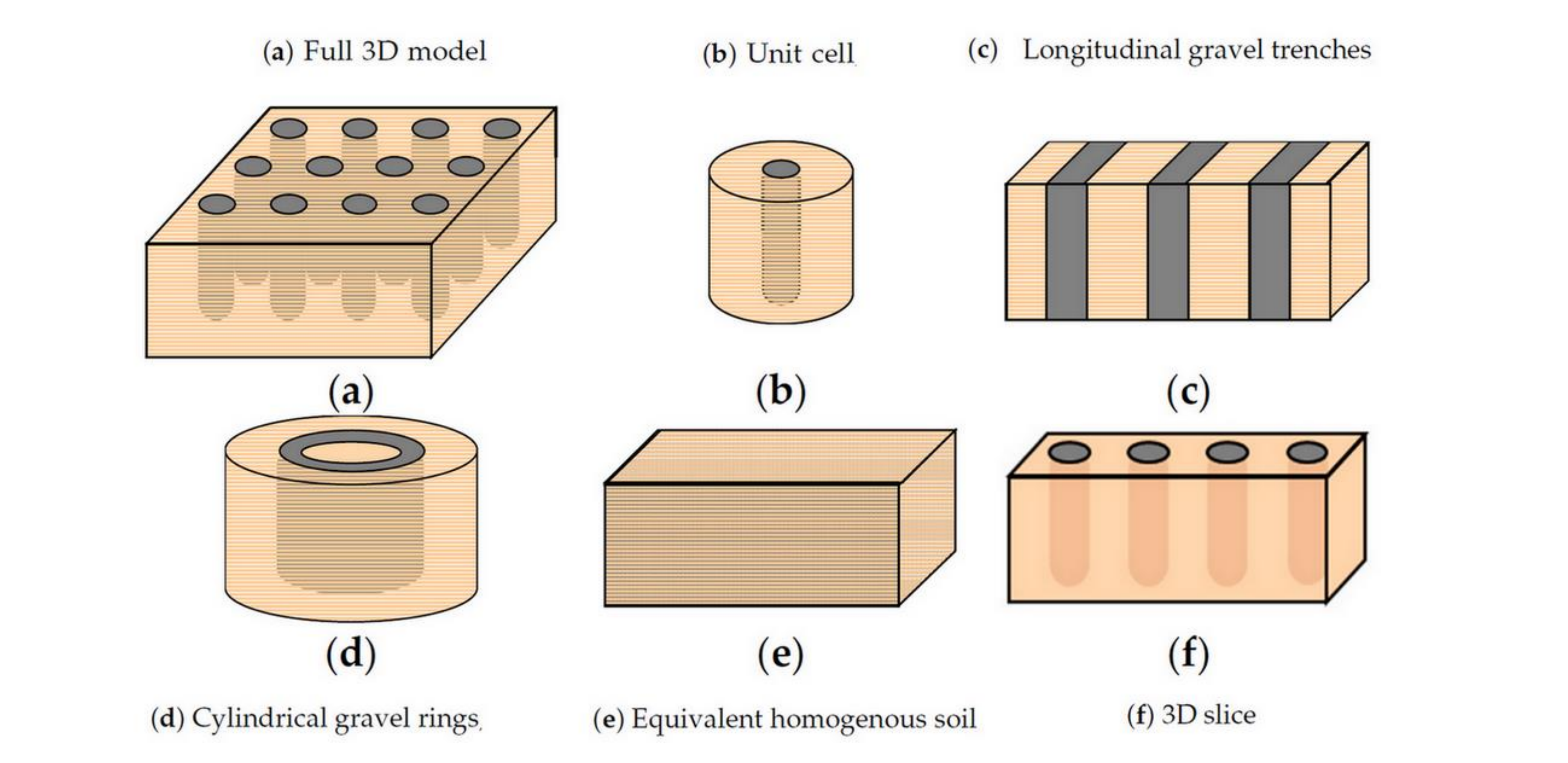
STONE COLUMNS MODELLING - 1

An illustration of a model as simplifications of reality

Real Geometry of the Problem



Stone Columns Modelling (simplifications of reality)

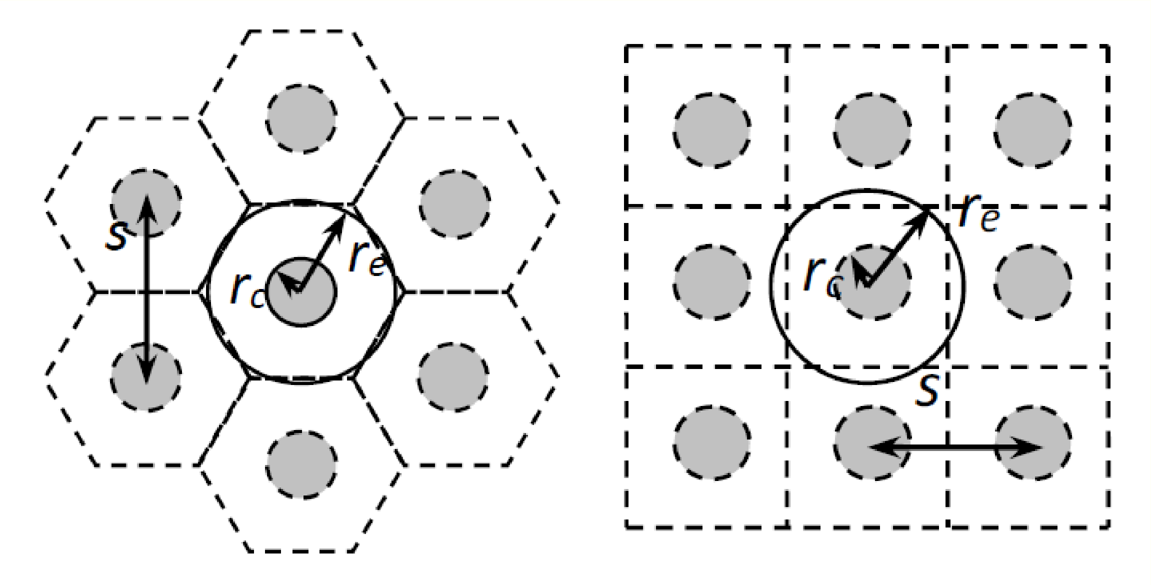


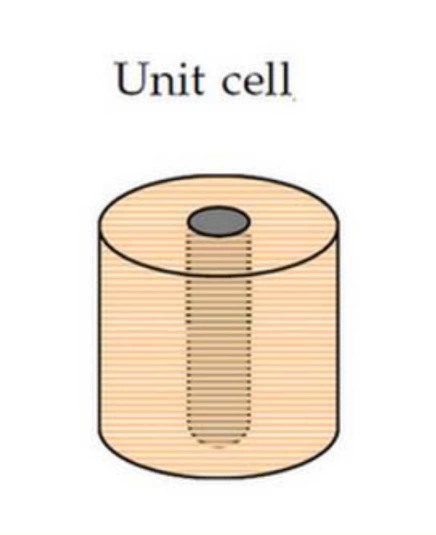
Stone Columns Modelling (1- Unit cell)

Simplification of the unit cell to axial symmetry conditions

- de = 1.05-1.13 s for triangular and square grids, respectively

Unit cell : Only one column and its corresponding surrounding soil are studied

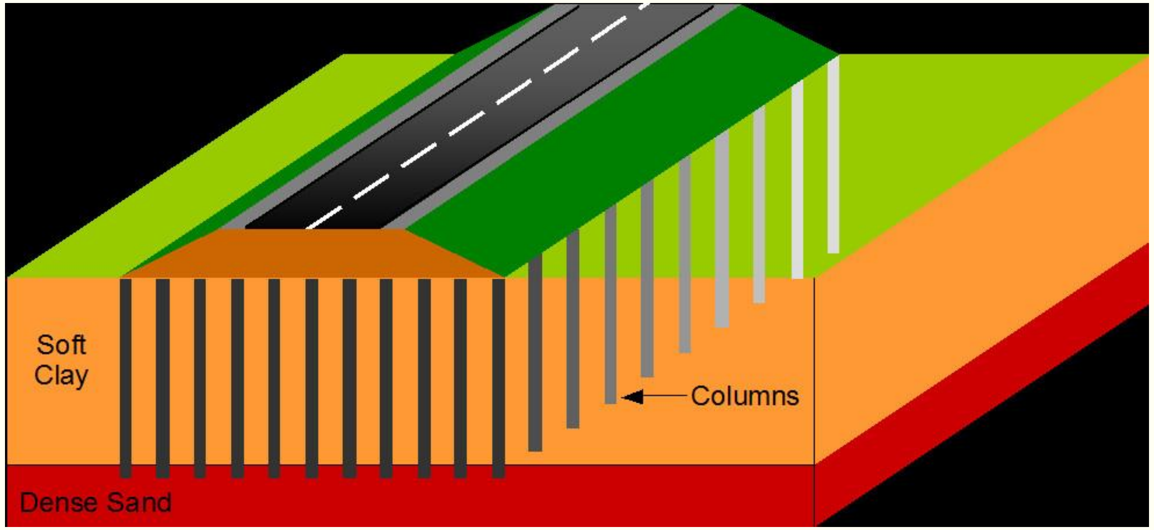




Stone Columns Modelling (1- Unit cell)

Unit cell applications:

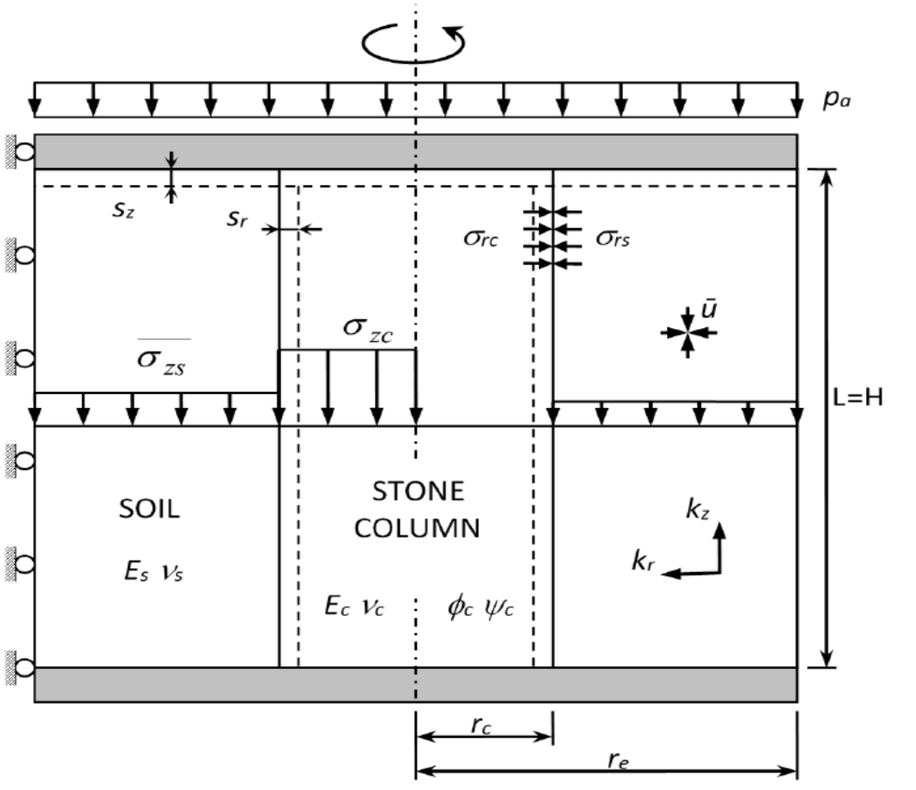
Usage of great number of columns, uniformly distributed in a wide area under a uniform loading (e.g., in the central part of an embankment on soft ground improved with stone columns)



Stone Columns Modelling (1- Unit cell)

Unit cell applications:

- ✓ **Analytical solution**
- ✓ **Consolidation Analysis**
- ✓ **Final Settlement**

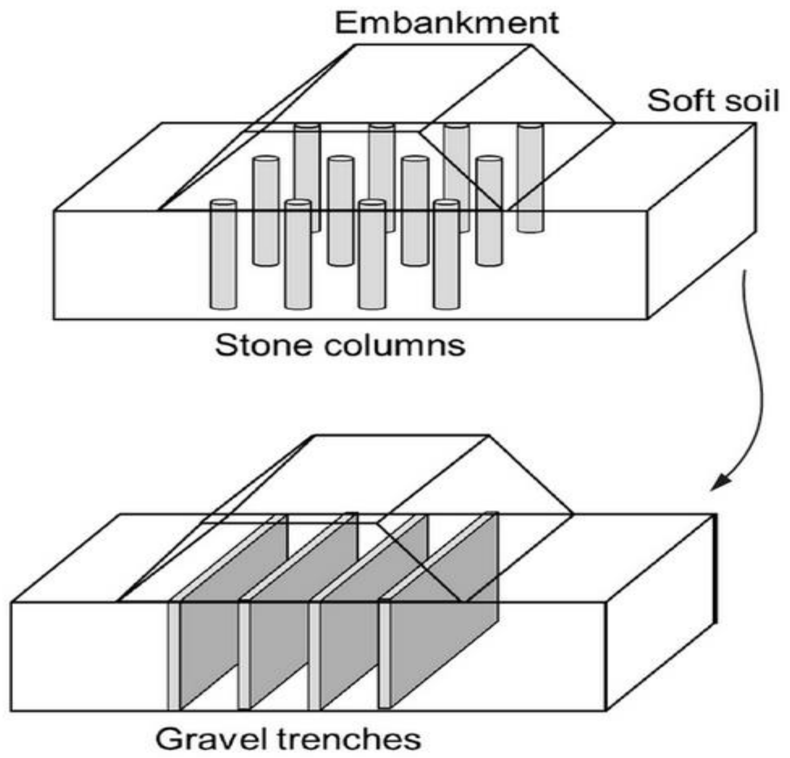


Unit cell model for analytical Solutions

Stone Columns Modelling (2- Longitudinal Gravel Trenches)

Longitudinal Gravel Trenches applications :

- ✓ 2D Plain Strain
- ✓ Stability
- ✓ Final Settlement
- ✓ Consolidation Analysis

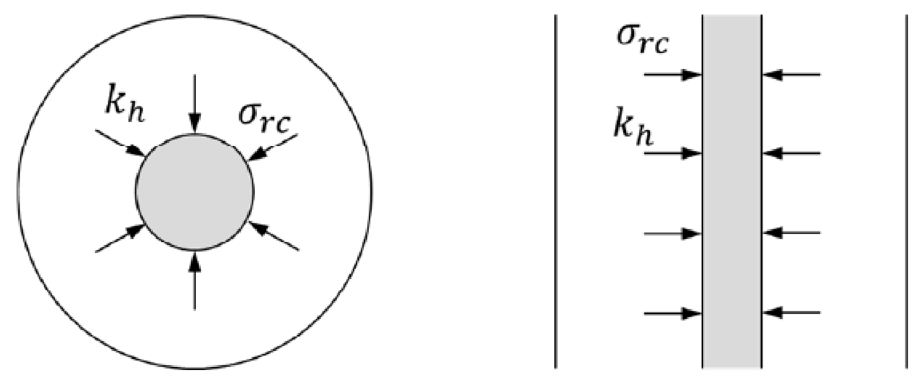


Longitudinal gravel trenches to model a stone column treatment in plane strain.

Stone Columns Modelling (2- Longitudinal Gravel Trenches)

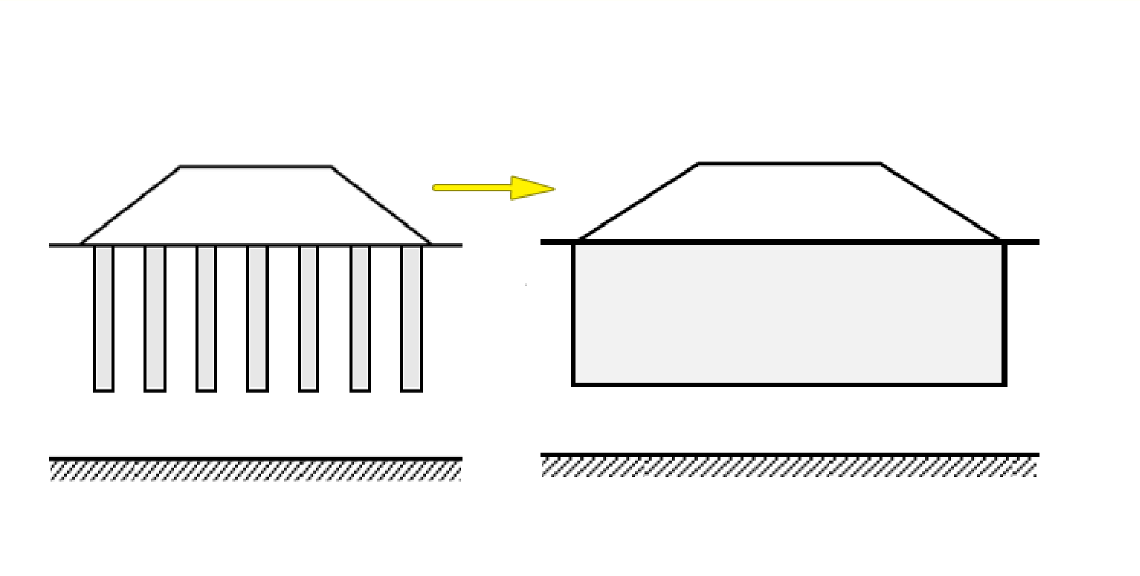
Longitudinal Gravel Trenches limitations :

- Different confinement and seepage conditions for columns in axial symmetry and plain strain conditions



Homogenization :

- Replacing the stone columns and the soft soil by an equivalent homogeneous soil with improved properties.



- ❑ This model simplifies enormously the geometry of the problem

$$E_m = E_s(1 - a_r) + E_c a_r$$

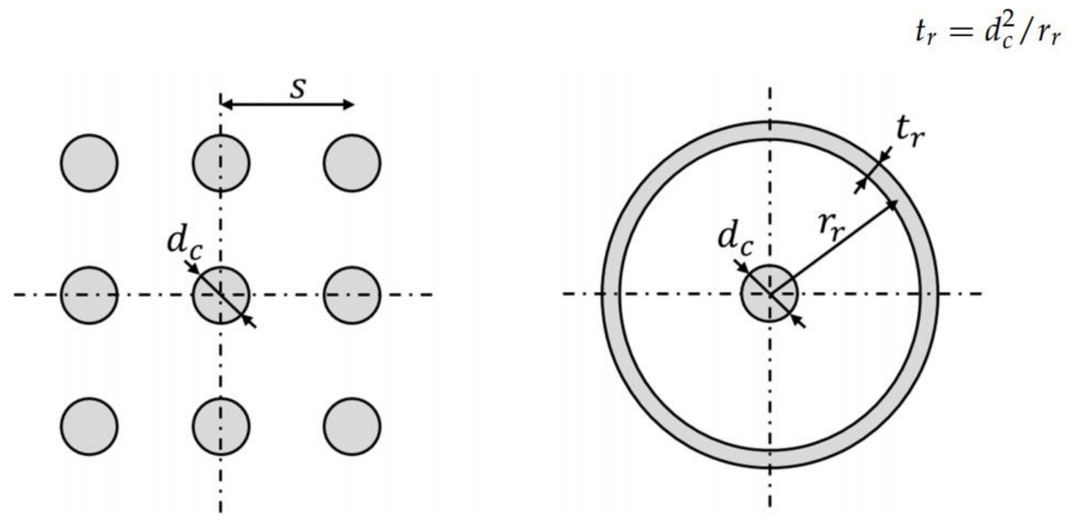
Stone Columns Modelling (4- Gravel Rings)

Gravel Rings applications :

- ✓ **2D Axial Symmetry**
- ✓ **Circular Embankments**
- ✓ **Circular storage tanks**

the gravel ring surrounds the same area as that of the square formed by the 8 columns:

$$r_r = 2s / \sqrt{\pi}$$

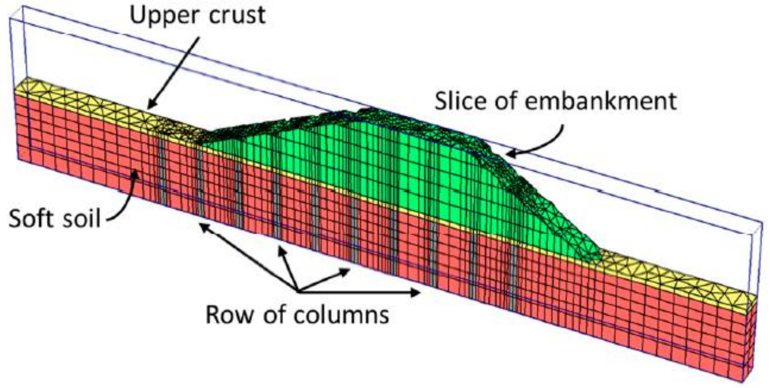


Transformation of stone columns in equivalent gravel rings.

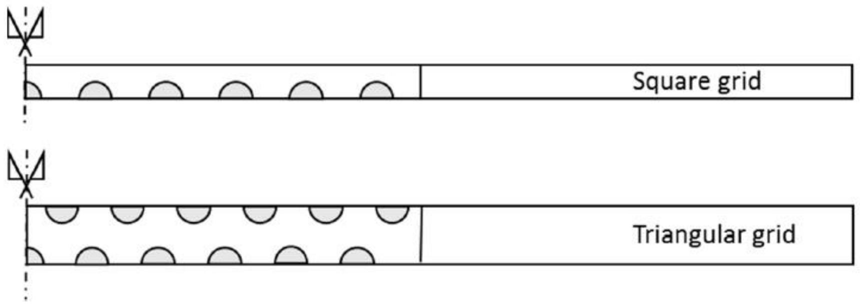
Stone Columns Modelling (5-Three-Dimensional Slice of Columns)

Three-Dimensional Slice of Columns applications :

- ✓ Consolidation
- ✓ Deformations
- ✓ Stability
- ✓ valid for both encased and non-encased columns



Finite element model of a 3D slice of columns



Numerical model of a slice of columns for triangular and square grids

Stone Columns Modelling (Suitability of Simplified geometrical models)

Suitability of simplified geometrical models to study different features of a stone column treatment for the foundation of an embankment.

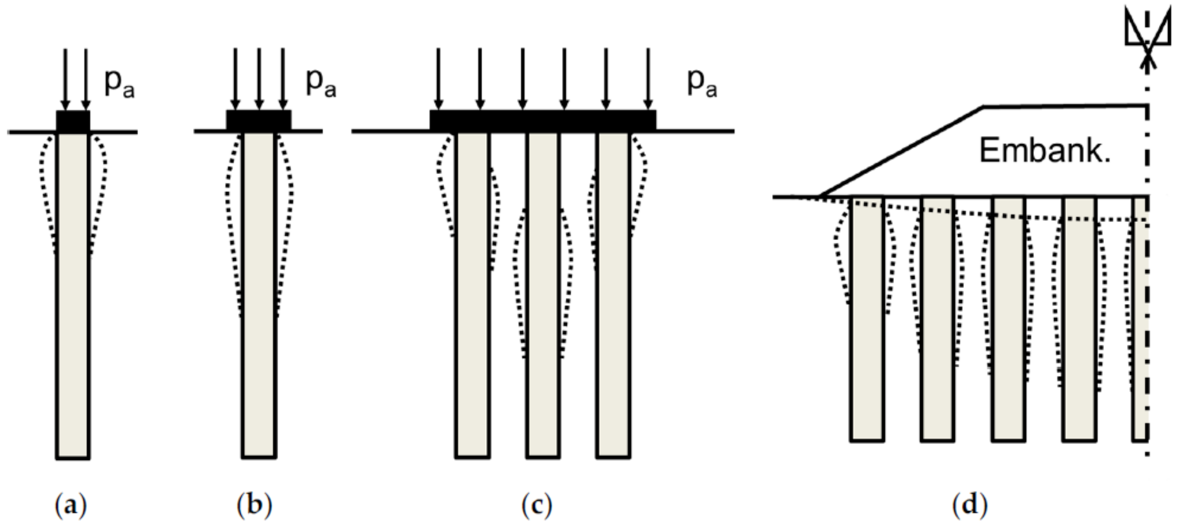
Geometrical Model	Final Settlement	Consolidation	Stability
Unit cell	***	***	-
Gravel trenches	**	**	**
Homogenization	**	*	*
3D slice	***	***	***

*** Completely suitable, ** Moderately suitable, * Slightly suitable, - Not suitable.

Stone Columns Modelling (6-Isolated Column)

Isolated Column: field or laboratory tests e.g. Plate load Test

- Area replacement is defined as ration between area of column and footing
- For ar=100% is not a realistic situation because it is more efficient to increase the loaded area (ar ≪ 100%)



Column deformation for different configurations: (**a**) Isolated column with a_r = 100%; (**b**) Isolated column with a_r < 100%; (**c**) Groups of columns beneath footing; (**d**) Column treatment beneath an embankment.

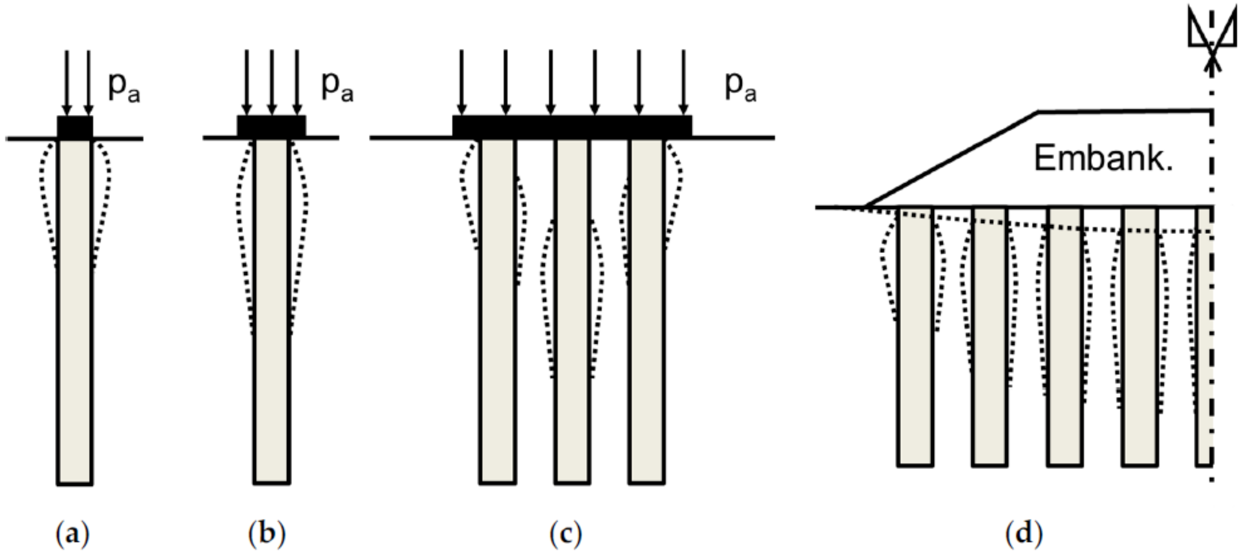
Stone Columns Modelling (6-Isolated Column)

Isolated Column applications :

✓ **Bearing Capacity of Stone**

$$\sigma_v^{max} \cong 20c_u \qquad (1)$$

- ➢ Equation 1 gives 20-50 tons for each stone column
- ➢ Equation (1) is valid for ar=100%

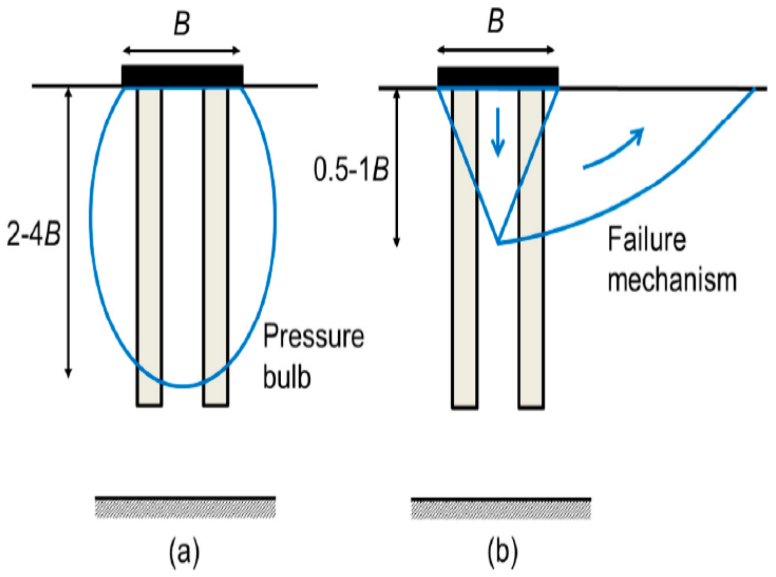


Column deformation for different configurations: (**a**) Isolated column with a_r = 100%; (**b**) Isolated column with a_r < 100%; (**c**) Groups of columns beneath footing; (**d**) Column treatment beneath an embankment.

Stone Columns Modelling (Critical Column length)

Critical Column length: for columns longer than the critical length, the settlement reduction or the bearing capacity of the footing does not notably change or improve.

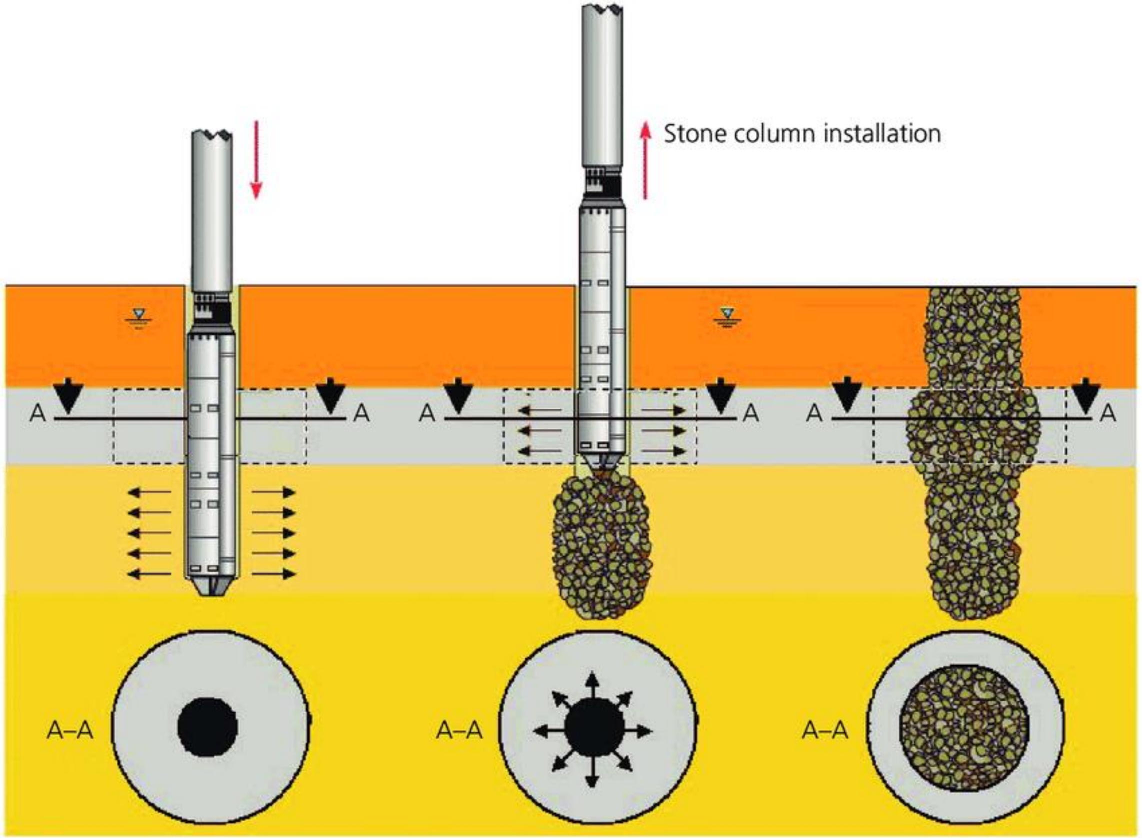
- ❖ when the bearing capacity is defined in terms of a critical settlement, the effect of extra columns outside the footing is only marginal.



Conceptual justification of critical column length in a homogenous soil layer: (**a**) for settlement reduction; (**b**) for bearing capacity.

Stone Columns Modelling (Column Installation Effects)

- Installation effects is less significance, the main improvement is caused by the inclusion of gravel
- ✓ Column installation, especially by vibro-displacement, also leads to an increase in the horizontal stresses.
- ✓ The increase in effective mean stress leads, in turn to an increase in the soft soil stiffness
- ❑ The remolding caused by column installation also alters the permeability of the soft soil in the vicinity of Column.
- ❑ Another related problem is column clogging



Stone Columns Modelling (Properties of the Columns)

Stress-dependent peak friction angles of dense gravel [93]

Type of Gravel	$\phi_{c,max}$ (°)	$\sigma_{c,max}$ (kPa)	$\phi_{c,min}$ (°)	$\sigma_{c,min}$ (kPa)	Remarks
Crushed lime stone	63.1	50	53.8	200	DS, Vibro SC
River gravel	58.8	50	51.9	200	DS, Vibro SC
River gravel, sub-round	57.1	50	50.9	200	DS, Vibro SC, $d_{60}/d_{10} = 2.6$
Rivel gravel, sub-round	59.2	50	53.2	200	DS, Vibro SC, $d_{60}/d_{10} = 2.1$
Rivel gravel, crushed	60.4	50	55.2	200	DS, Vibro SC
Dolomite	64.0	15	43	500	TX, $\gamma = 17$ kN/m^3, [90]
Dolomite	54.0	15	40	500	TX, $\gamma = 15$ kN/m^3, [90]
Sandstone	60.1	27	45.6	695	TX, [92]
Basalt	64.2	27	45.6	695	TX, [92]
Basalt	71.8	8	45.6	240	TX, $d_{50} = 30$ mm, [91]
Basalt	70.0	8	51.1	120	TX, $d_{50} = 30$ mm, [91]

DS: Direct shear test; TX: Triaxial test; Vibro SC: dense gravel for vibrated stone columns [93]; d_{60}/d_{10}: uniformity coefficient.

Stone Columns Modelling (Properties of the Columns)

Parameters used to model stone columns in numerical analyses

ϕ_c (°)	ψ_c (°)	E_c (MPa)	ν (-)	m (-)	γ_d/γ_{sat} (kN/m^3)
41	-	29.2	0.2	0.59	18.6/21.6
35	-	67.5	0.3	-	-
40–35	3	50	0.3	-	-
45	0	100	0.3	-	19/19
48	26	2.5	0.3	-	16/-
40	-	30	0.3	-	15/15
40	0	30	0.3	-	-/15
35	5	25	0.2	0.3	20/23.5
42	12	35	0.2	-	16/19
46	10	22	0.15	0.25	-
45	15	70	0.2	0.3	19/19

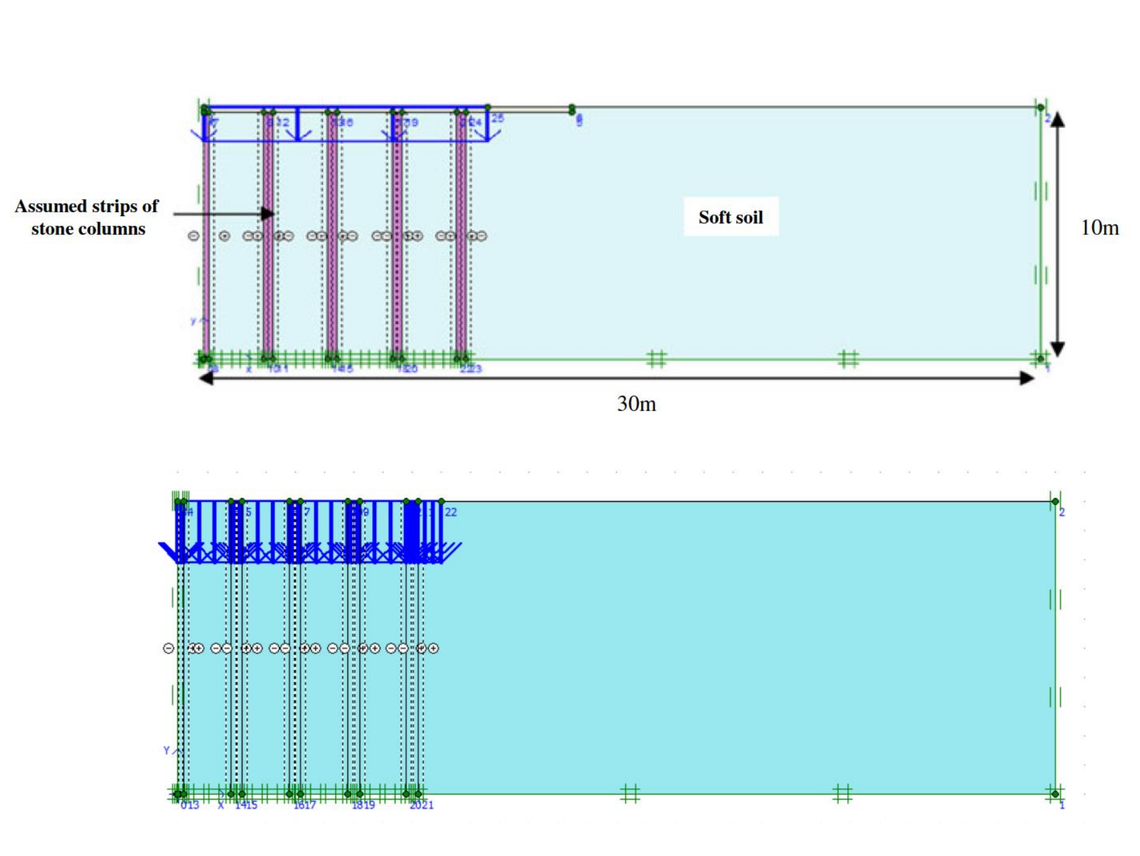
The reference pressure for the stiffness is 100 kPa; m: Exponent of the power law used to reproduce the stress dependent stiffness.

NUMERICAL MODELLING PLAXIS 2D - 2

Verification

Numerical Modelling (Input 2d modelling)

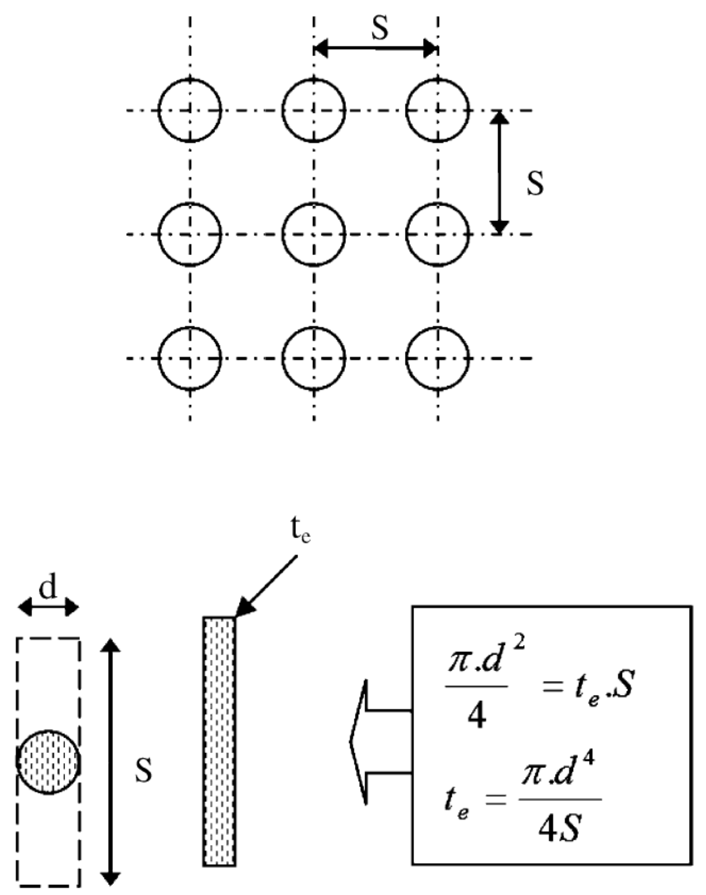
- it was assumed that the raft is rigid and both the stone column and soft clay undergo the same amount of settlement



Numerical Modelling (2d technique modelling)

Plain Strain Model :

Square Pattern

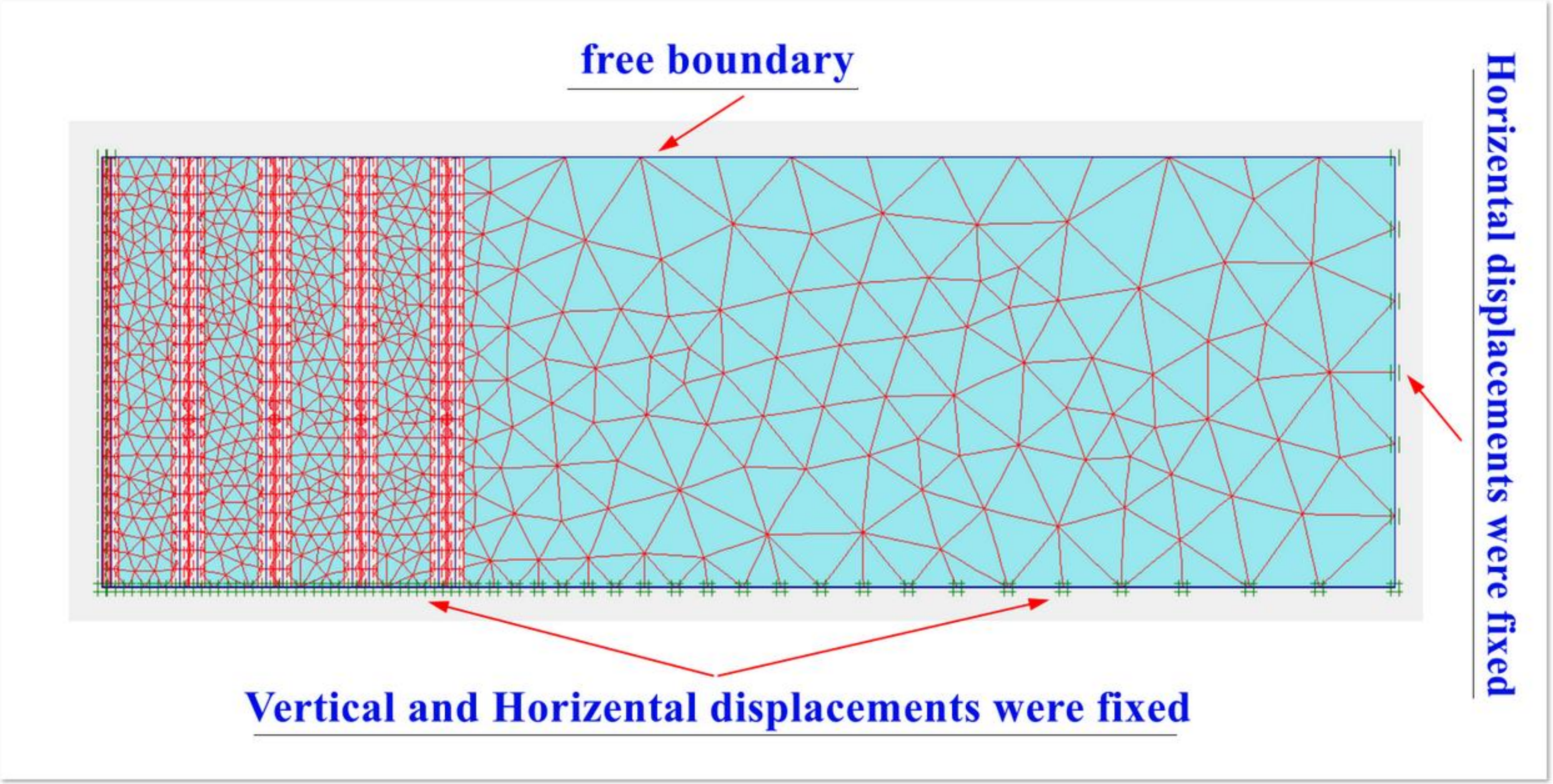


Numerical Modelling (Material properties)

	E (Kpa)	v	ϕ (°)	ψ (°)	c (Kpa)	γ (kN/m^2)	R_{inter}
Soft clay	4,000	0.35	21	0	5	17	0.7
Stone column	55,000	0.3	43	10	0	19	0.9
Sand	20,000	0.3	30	4	0	16	-

Parameters used in the numerical analysis

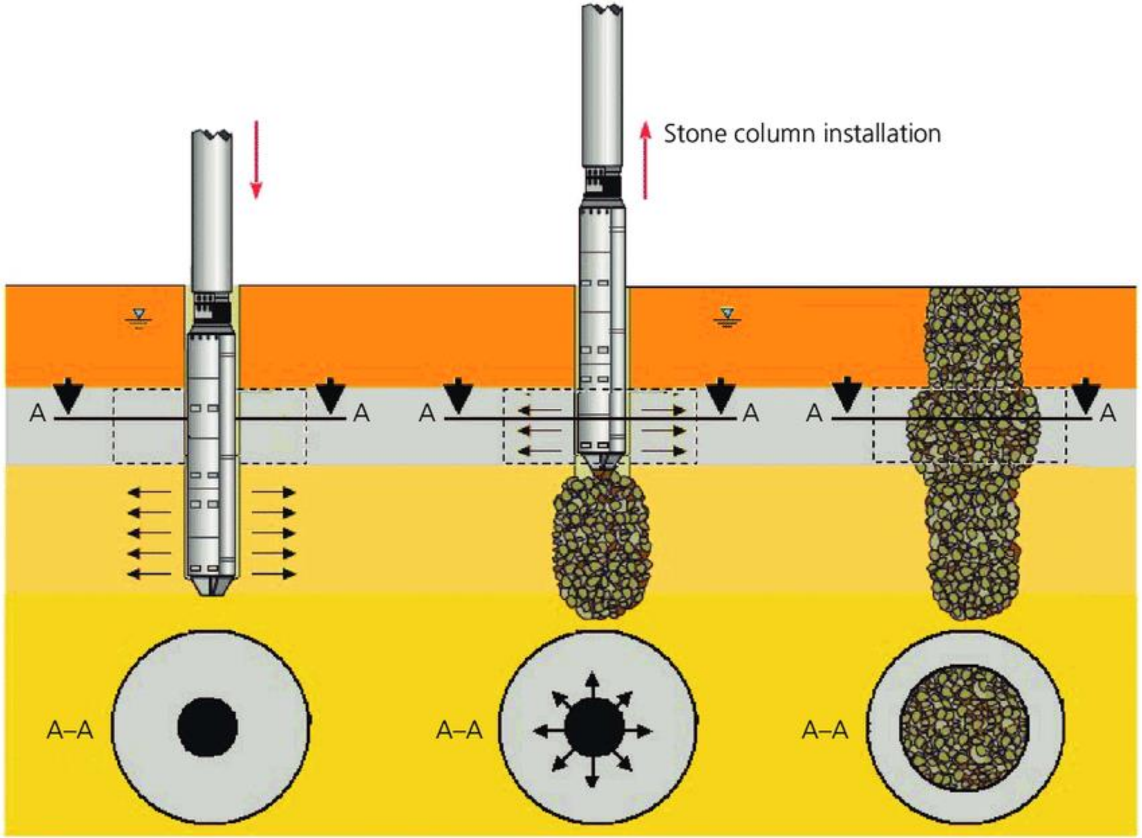
Numerical Modelling (Mesh and Boundary Condition)



Numerical Modelling (Column Installation Effects)

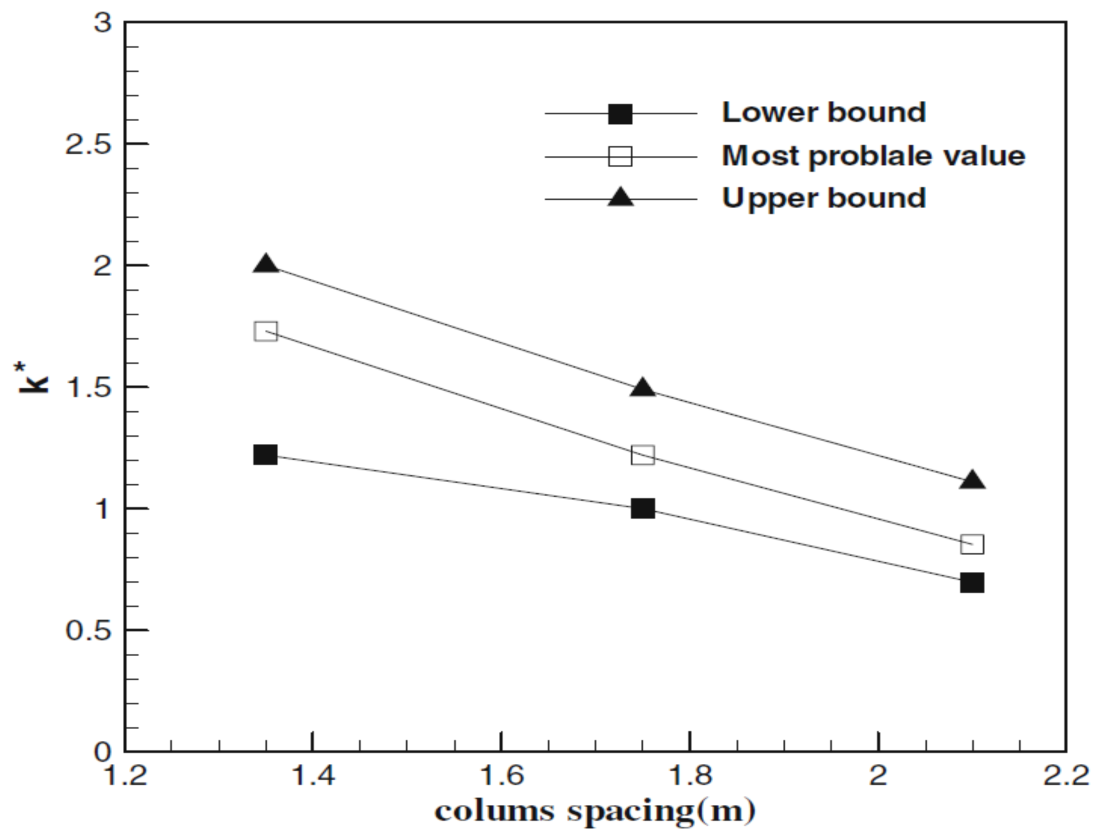
- Column installation may be considered altering the at-rest earth pressure coefficient of the natural soft soil. Published values vary between 0.4 and 2.5, with average values slightly above 1.
- if the numerical model does not consider a stress-dependent constitutive model for the soft soil, its stiffness should be increased correspondingly.

✓ The increase in effective mean stress leads, in turn to an increase in the soft soil stiffness.



Numerical Modelling (Column Installation Effects)

- **Variation of at-rest earth pressure with Columns Spacing**

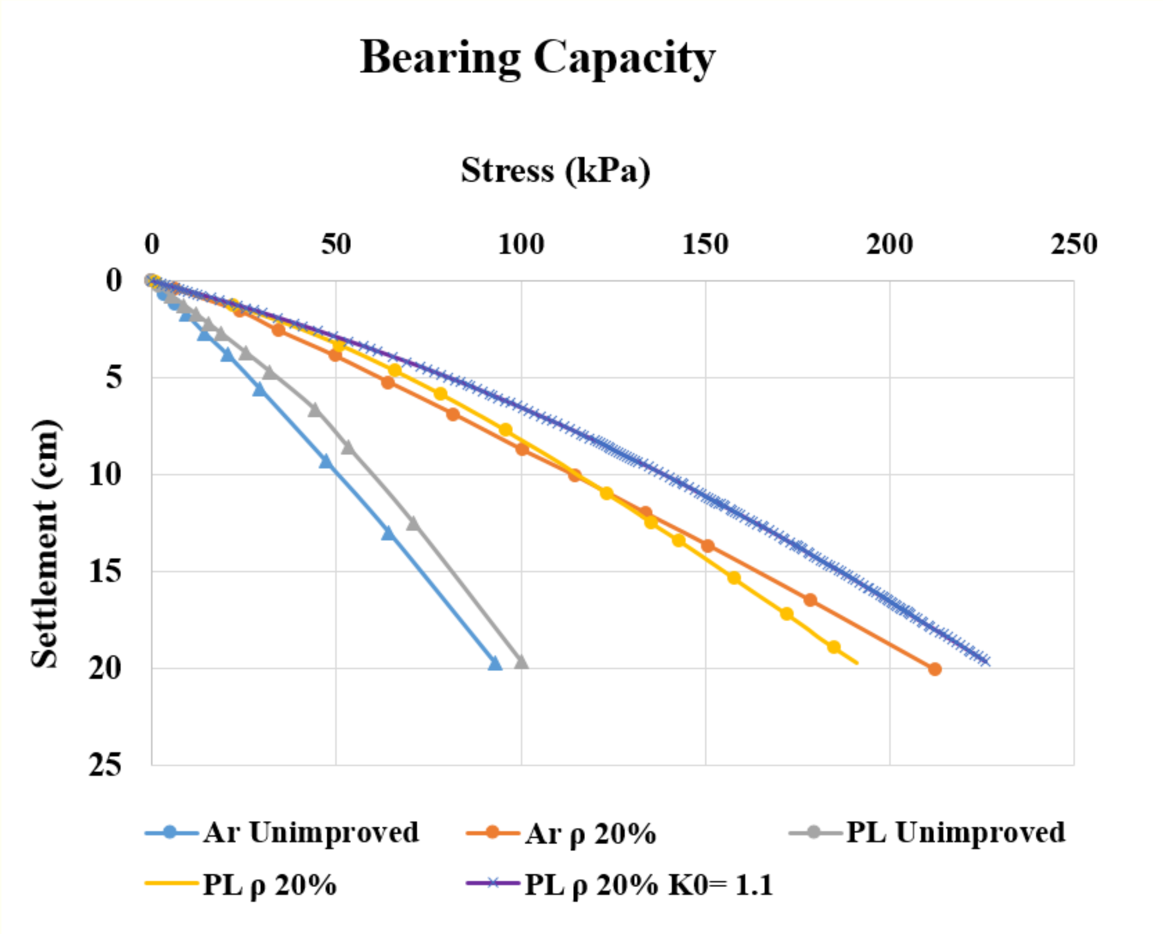


Variation of K^* with columns spacing (Elshazly et al. 2007)

Numerical Modelling (Verification)

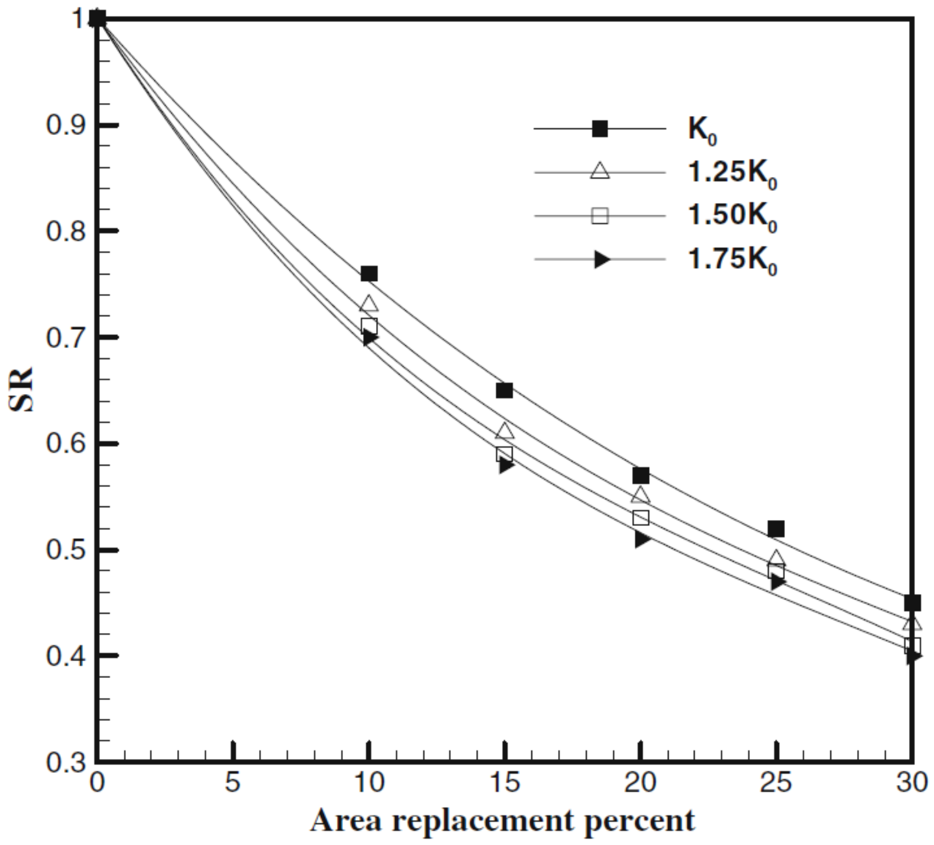
Verification:

- ✓ Area replacement 20 %
- ✓ Stone Column Diameter 1 m
- ✓ Stone Spacing 2.1 m
- ✓ K0 before installation 0.606
  and after installation 1.1



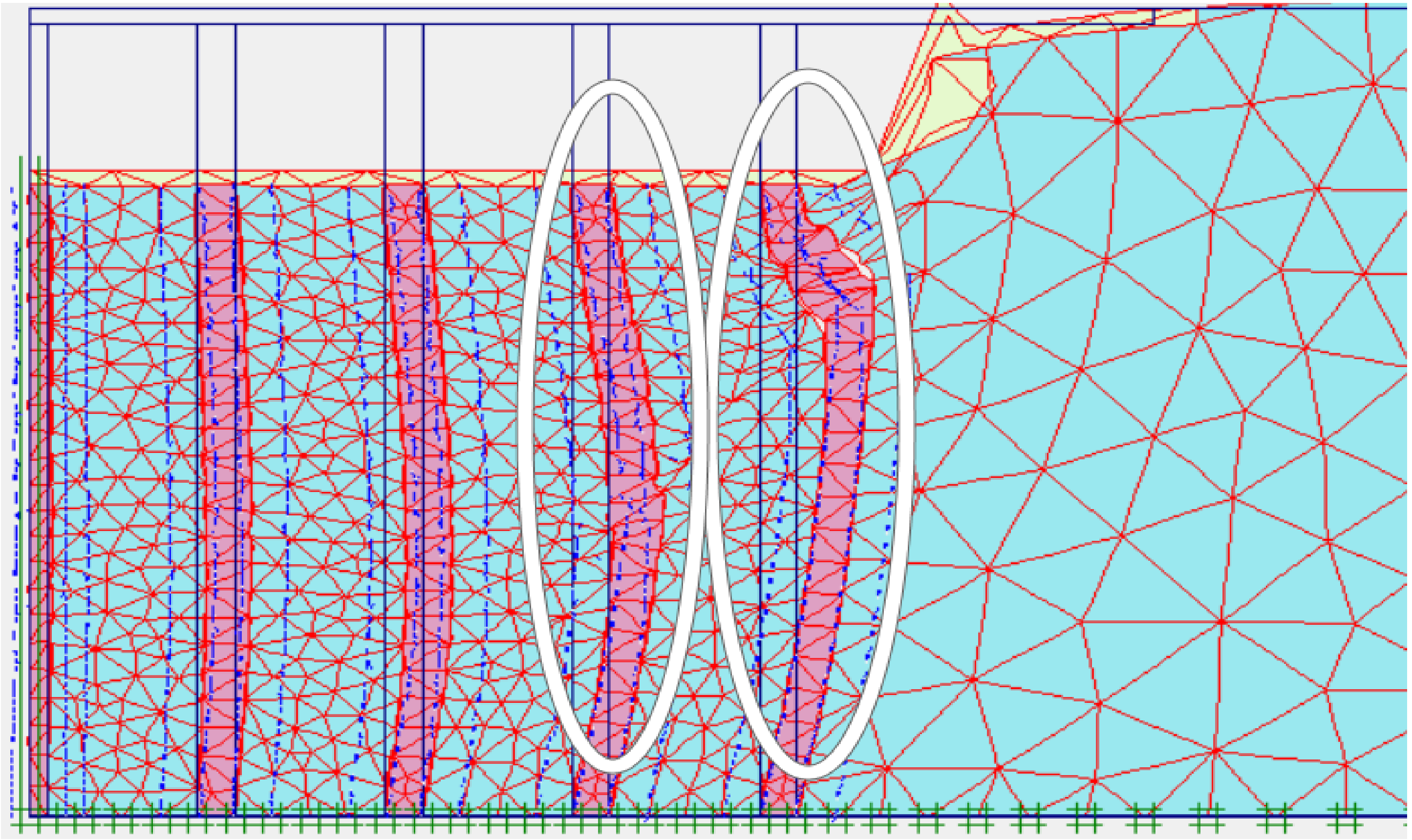
Numerical Modelling (Settlement ratio)

- stone column improves the ground mainly due to the higher stiffness of the columns compared to the soil.
- stone column decreases largely settlement even if the insertion of stone columns into weak soils be considered just a replacement operation without any effect on surrounding soft soil.



Effect of soil compaction on SR

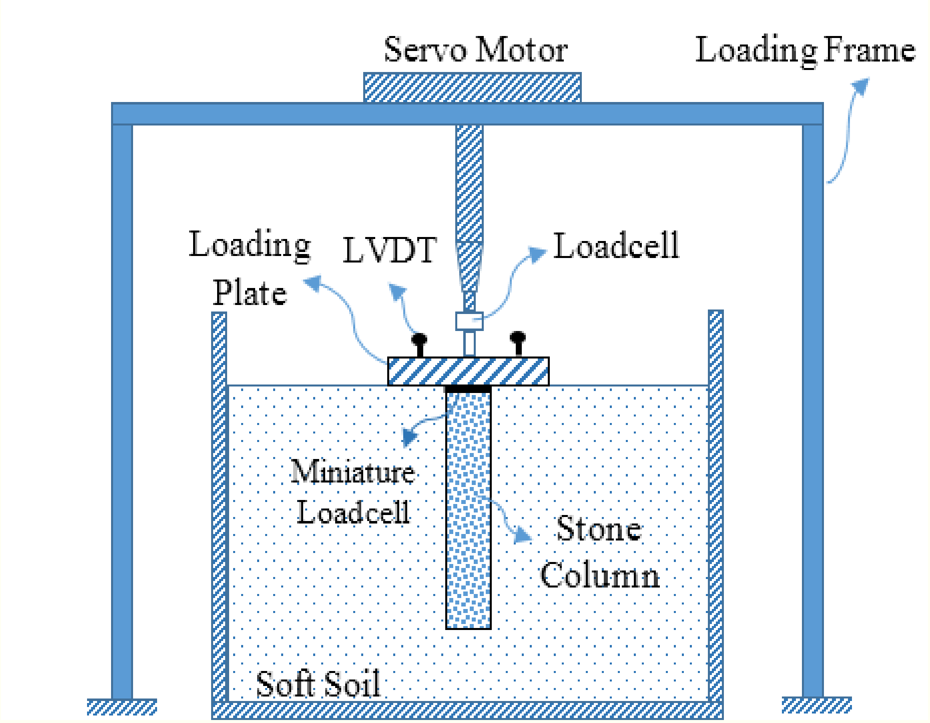
Numerical Modelling (Failure mechanism)



PHYSICAL MODELLING

3D modelling

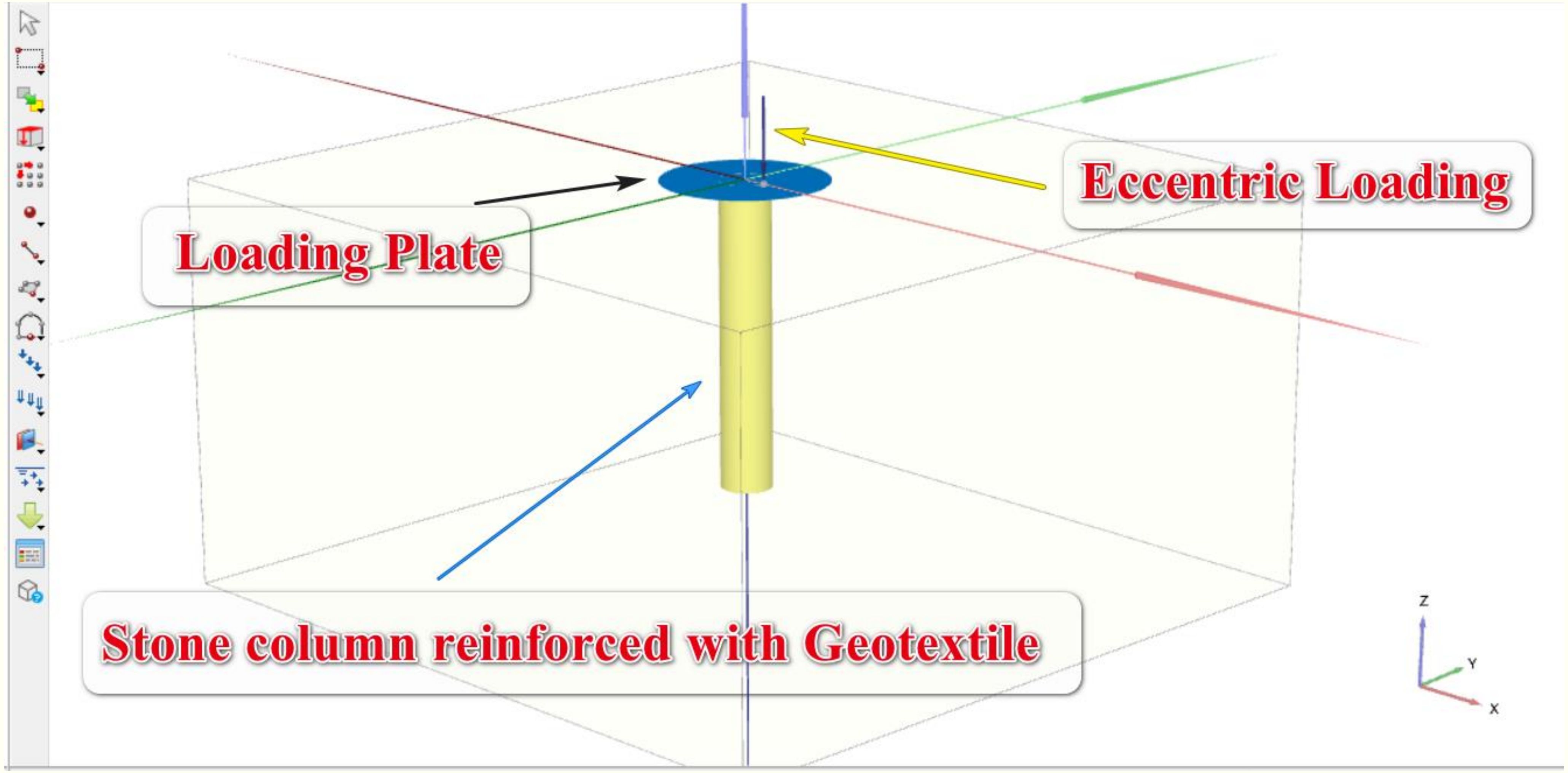
Physical Modelling (3D Modelling)



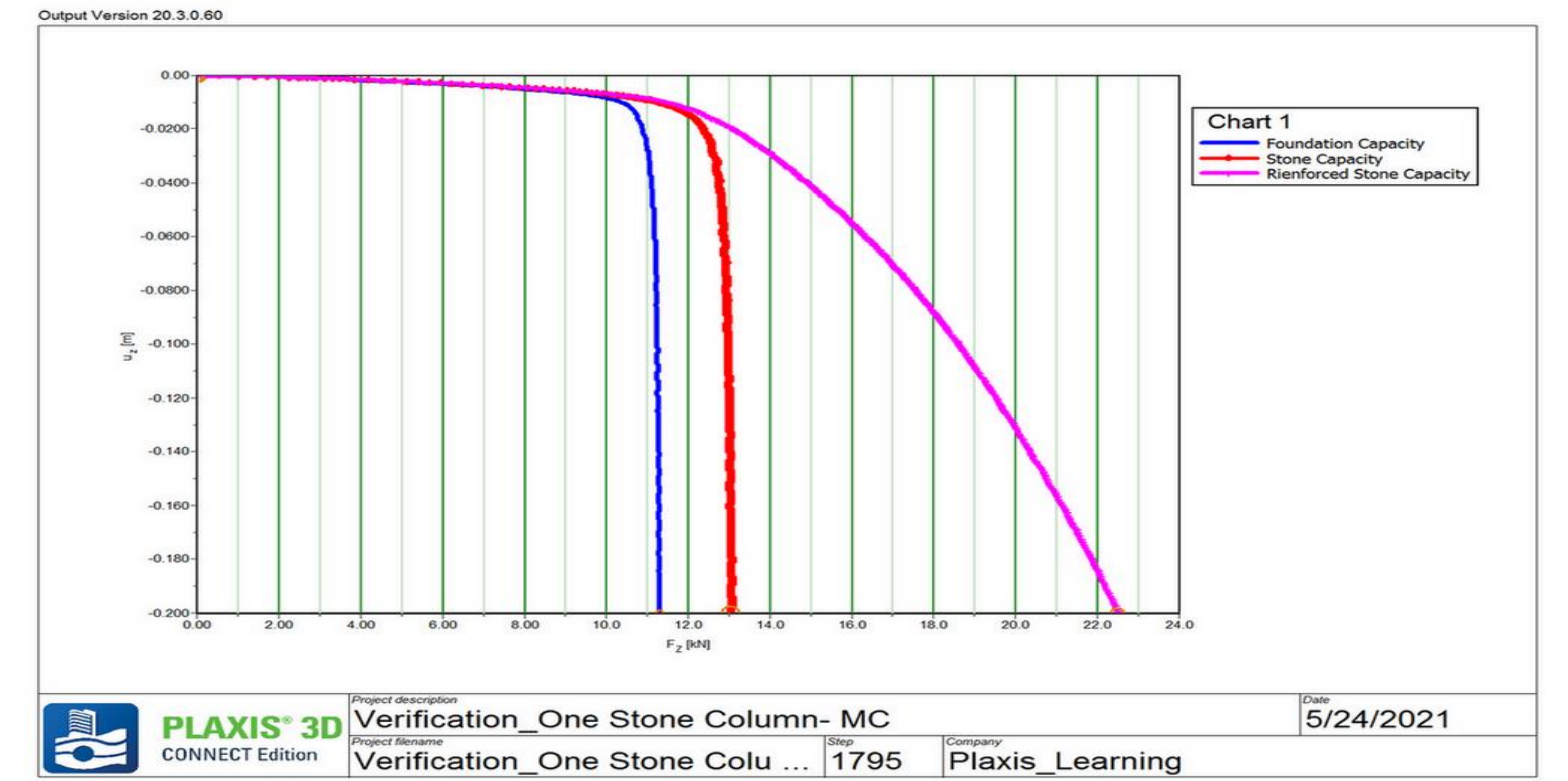
Physical Modelling (3D Modelling)

Physical Modelling (3D Modelling)

Physical Modelling (3D Modelling)



Physical Modelling (3D Modelling)



Refrences

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More information about the lecturer

: @Zaheri_Afshin

: @Plaxis_learning

: Aparat.com/Plaxis_learning

e-mail: afshinzaheri.as@gmail.com


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