GROUND IMPROVEMENT WORKSHOP 11-12 JUNE 2010

PERTH, AUSTRALIA

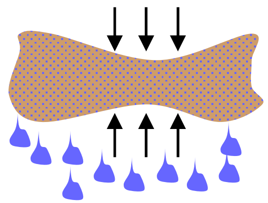
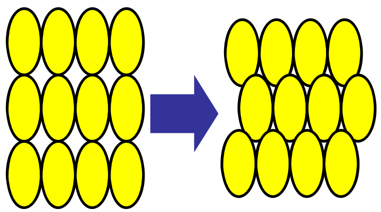
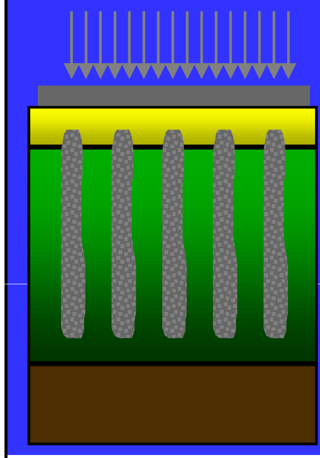
CONCEPT AND PARAMETERS WITH ADDED MATERIAL

PRESENTED BY

SERGE VARAKSIN

CHAIRMAN OF T.C. GROUND IMPROVEMENT

Soil Improvement Techniques

	Without added materials	With added materials
Cohesive soil **Peat , clay …**	1 Drainage 2 Vacuum 	4 Dynamic replacement 5 Stone columns 6 CMC 7 Jet Grouting 8 Cement Mixing
Granular soil **Sand , fill**	3 Dynamic consolidation 4 Vibroflottation 	

Dynamic Replacement

General job site view

Port of Beirut, Lebanon

CONCEPT

-Very soft to stiff soils

-Unsaturated soft clays

-Thickness of less than 6 meters

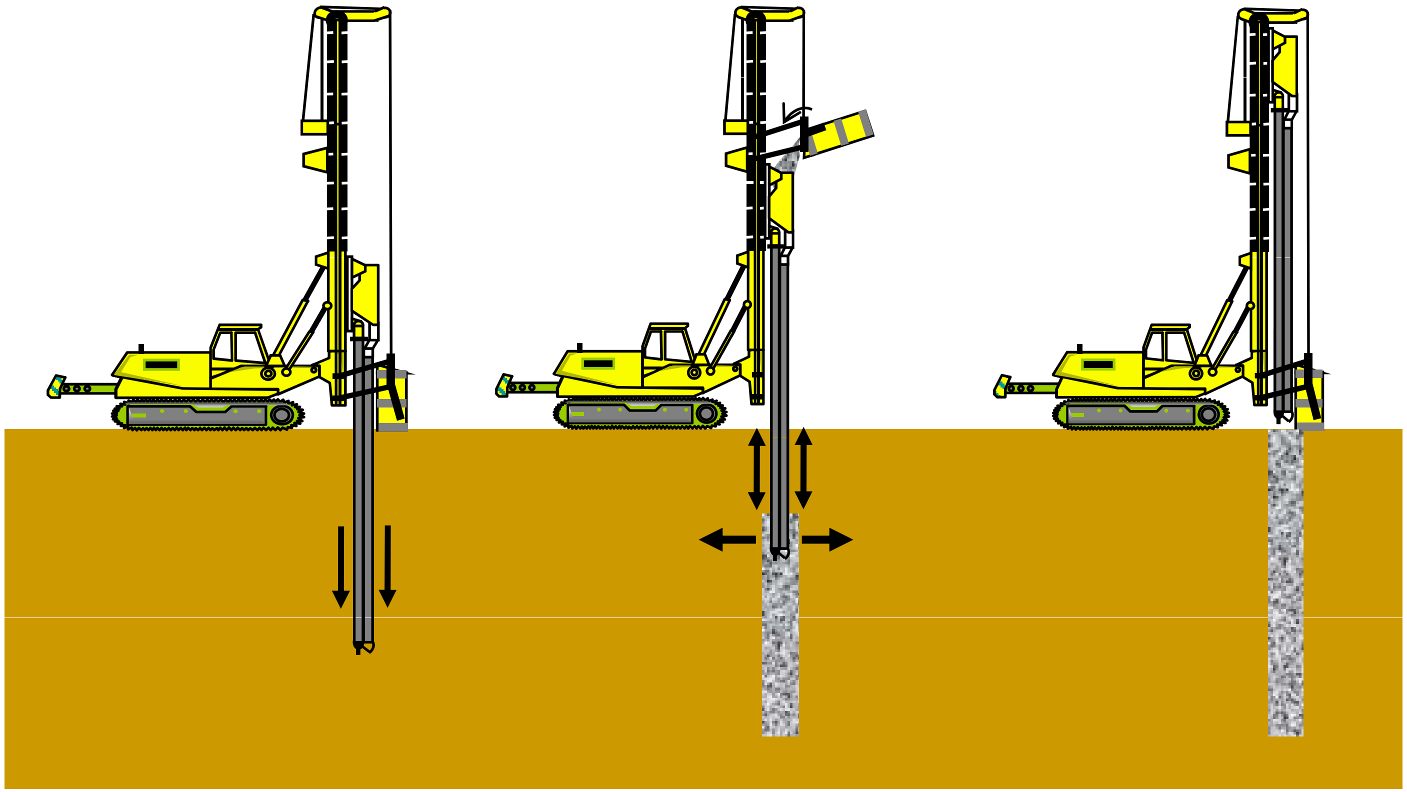
-Arching layer available

PARAMETERS

-C, $\varnothing$, μ, E_y of soil, column and arching layers, grid

-or P_L, E_P, μ of soil, column and arching layers, grid

Stone Columns - Bottom Feed



Vibrator penetration

Material feeding

Vibration of material during extraction

Principle of the technology - bottom feed with air tank

Stone Columns - Bottom Feed

Stone Columns

bottom feed to 22 m depth

CONCEPT

-Soft to stiff clays

-Thickness up to 25 meters

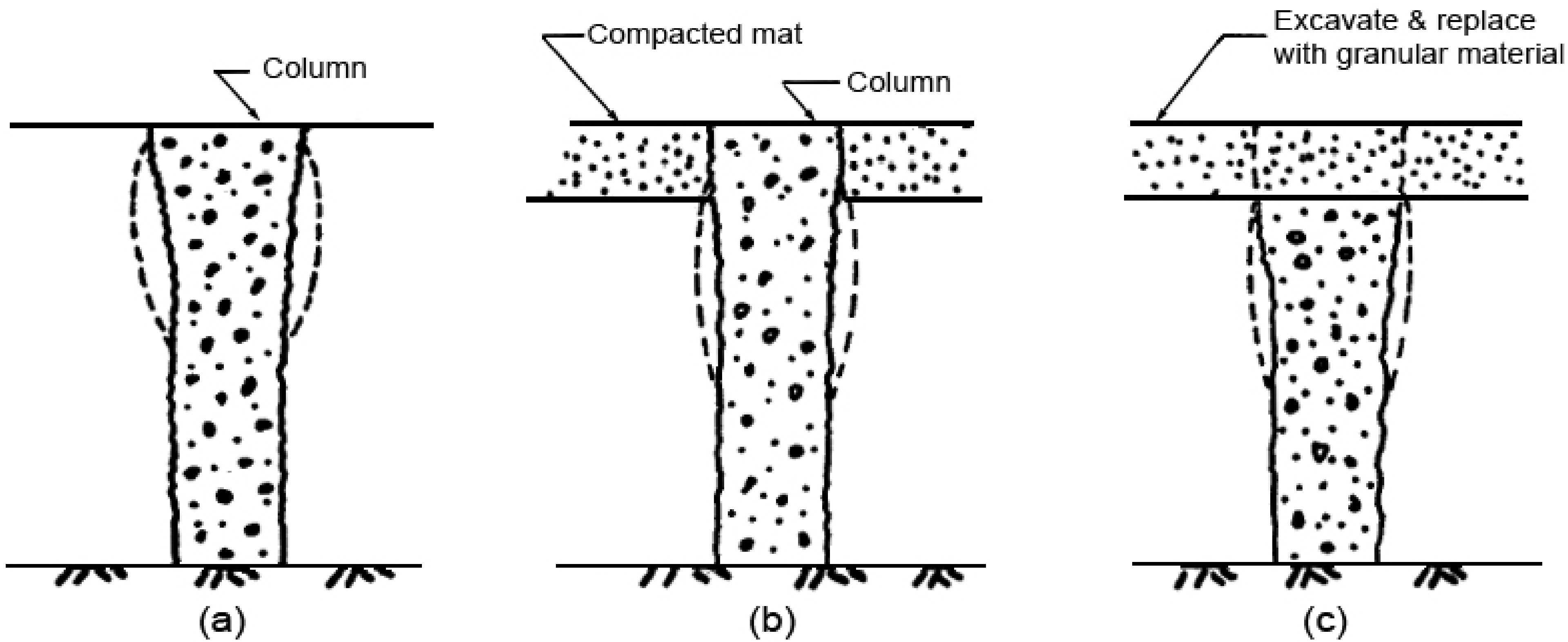
-Arching layer available

PARAMETERS

-C, $\varnothing$, μ, E_y of soil, column and arching layers, grid

-or P_L, E_P, μ of soil, column and arching layers, grid

Stone Columns: Bulging in very soft ground

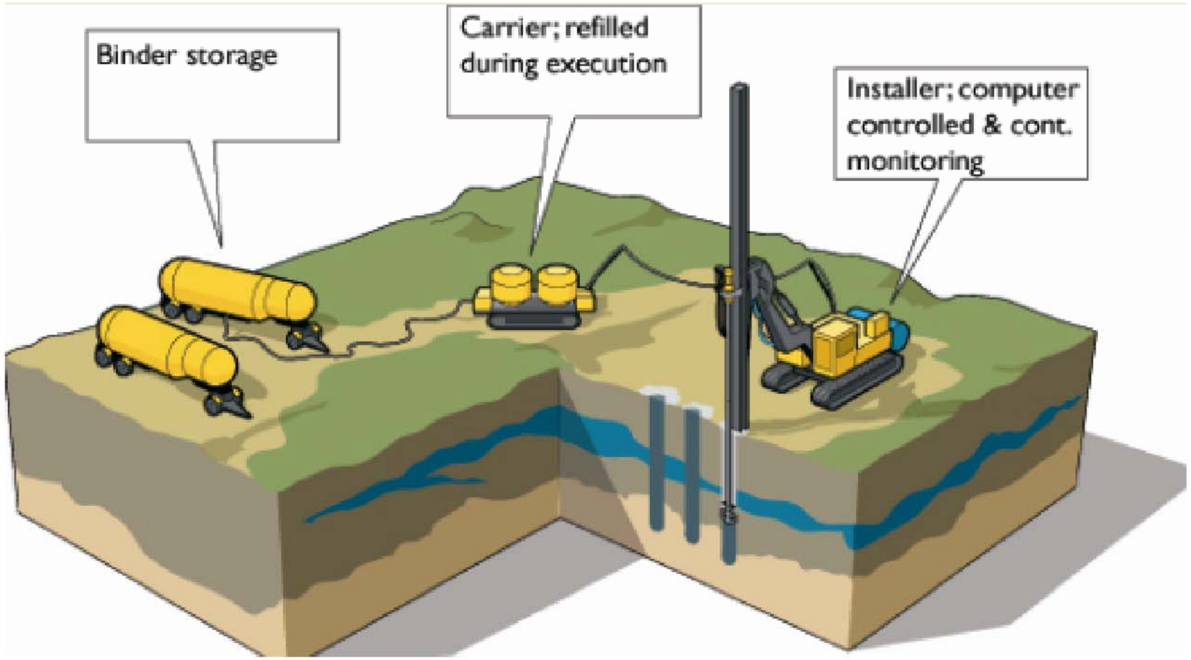


After Barksdale & Bachus, 1983

CONCEPT

The MDM process (1)

Site logistics



Initial idea

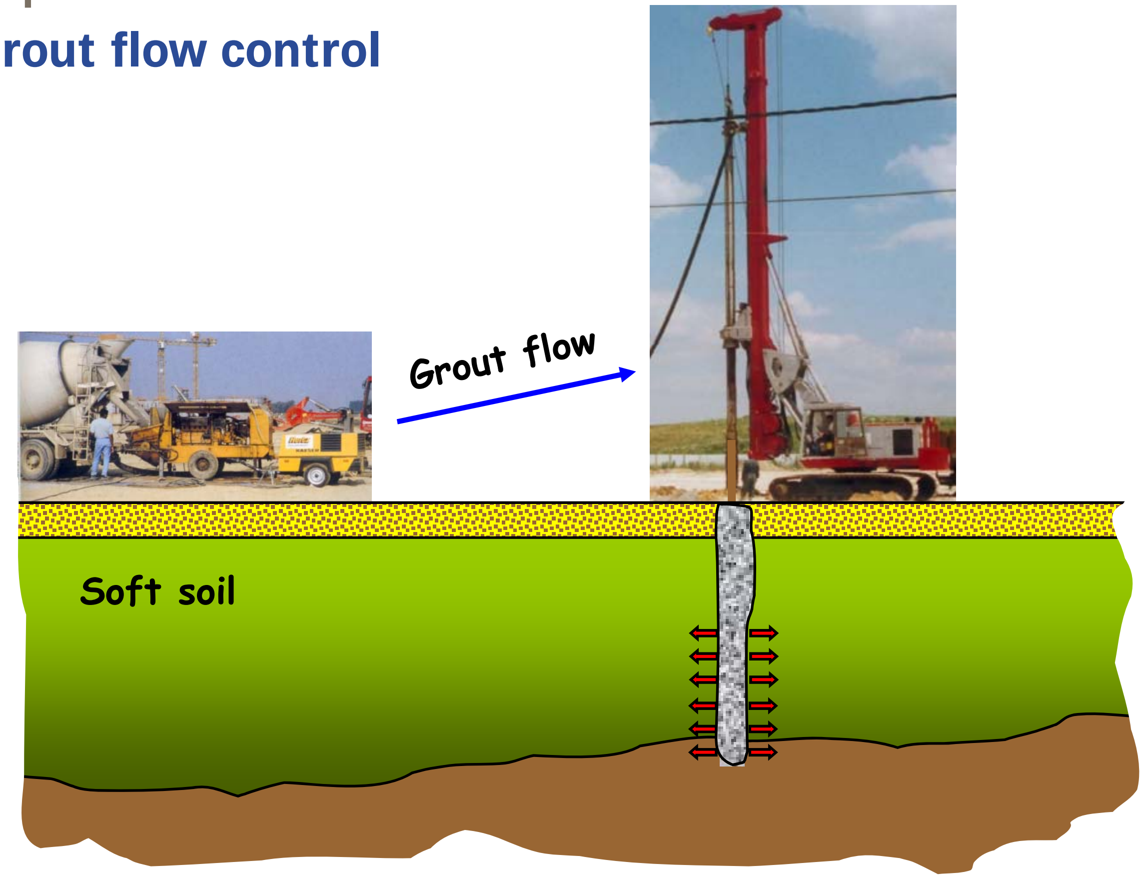
- **As usual, innovation comes from solving problems:**
  - **Project with bulging problem with Stone Columns in very weak soils (peat),**
  - **However principle of regular mesh of columns good,**

→ Idea to use adapted material so as to avoid bulging

- **Then additional benefits investigated, such as:**
  - **Relative low cost,**
  - **High speed of execution,**
  - **High capacity to mitigate settlement**

CMC - Execution

- **Fleet of specialized equipment**
  - Displacement auger → quasi no spoil
  - High torque and pull down
- **Fully integrated grout flow control**



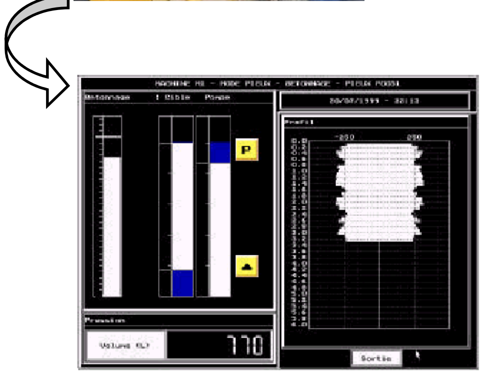
CMC - Execution

CMC - Typical Testing

- **Load testing on isolated CMC**
  - **Checking of individual capacity,**
  - **Checking of adequate soil parameters taken into account.**

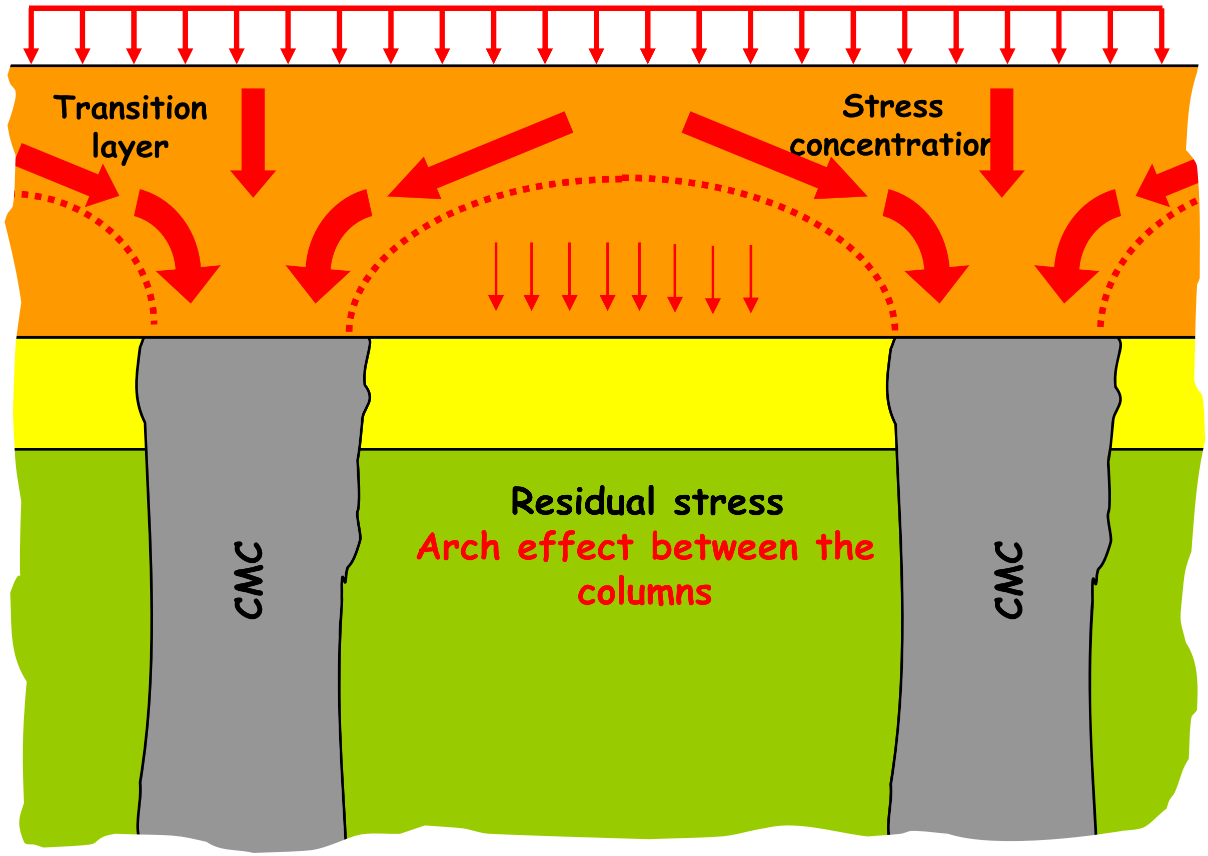
- **Compression tests on material**
  - **Checking of good grout resistance**

- **Data recording system during execution**
  - **Recording of drilling parameters → Checking of anchorage,**
  - **Recording of grouting parameters → No necking**



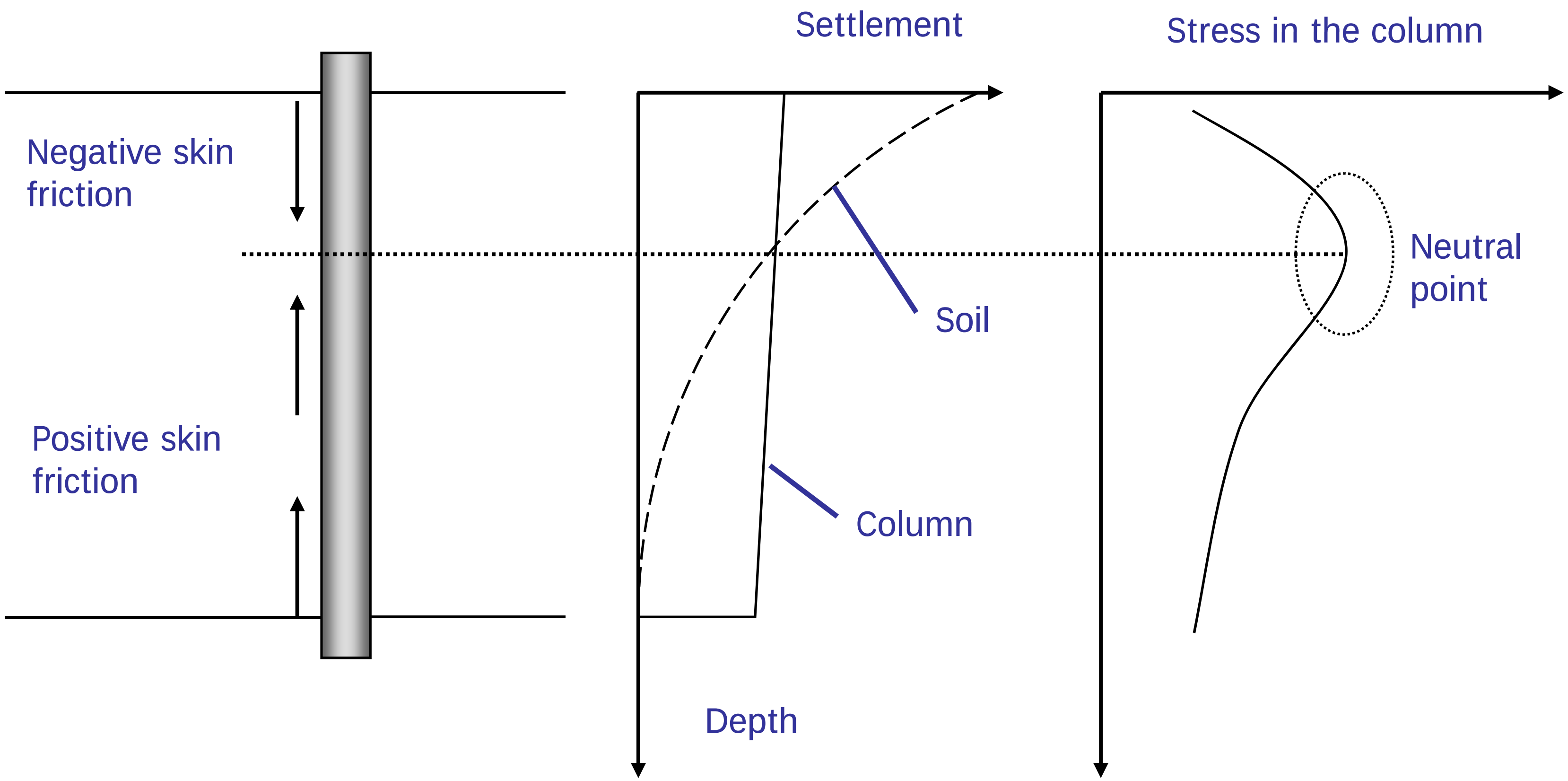
CMC Principle

- Create a composite material: soil + rigid inclusions (CMC) with:
  - Increased bearing capacity
  - Increased elastic modulus
- Transfer the load from structure to CMC network with a transition layer

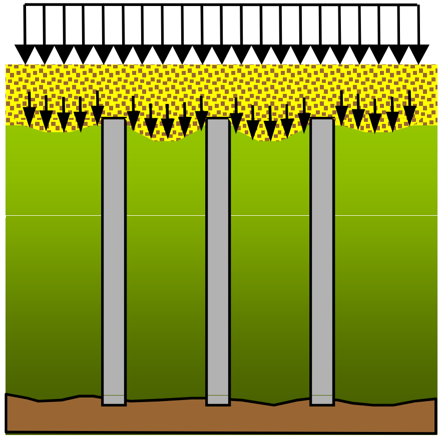


CMC - Basic behavior under uniform load

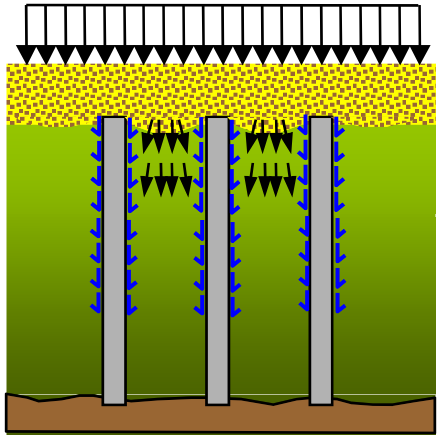
- **Negative skin friction allows to develop a good arching effect**



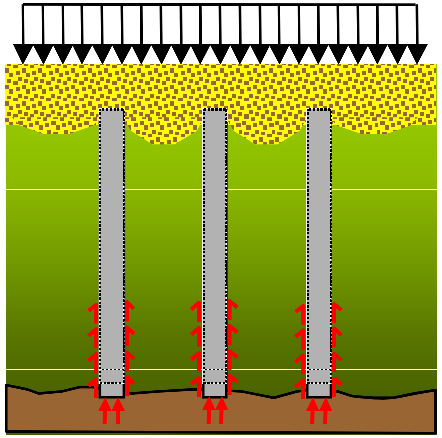
CMC - Arching effect



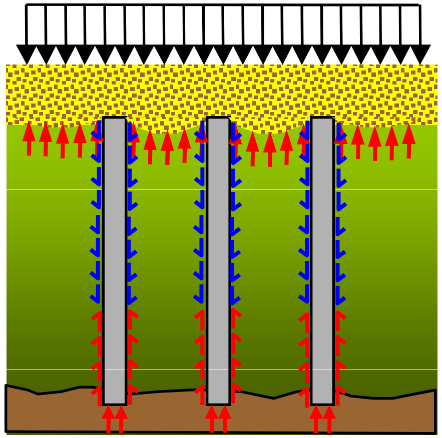
Settlement of soft soil



Transfer of load to CMC by negative skin friction

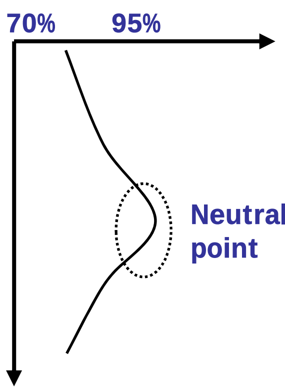


Settlement of CMC in substratum and transfer of load by positive friction



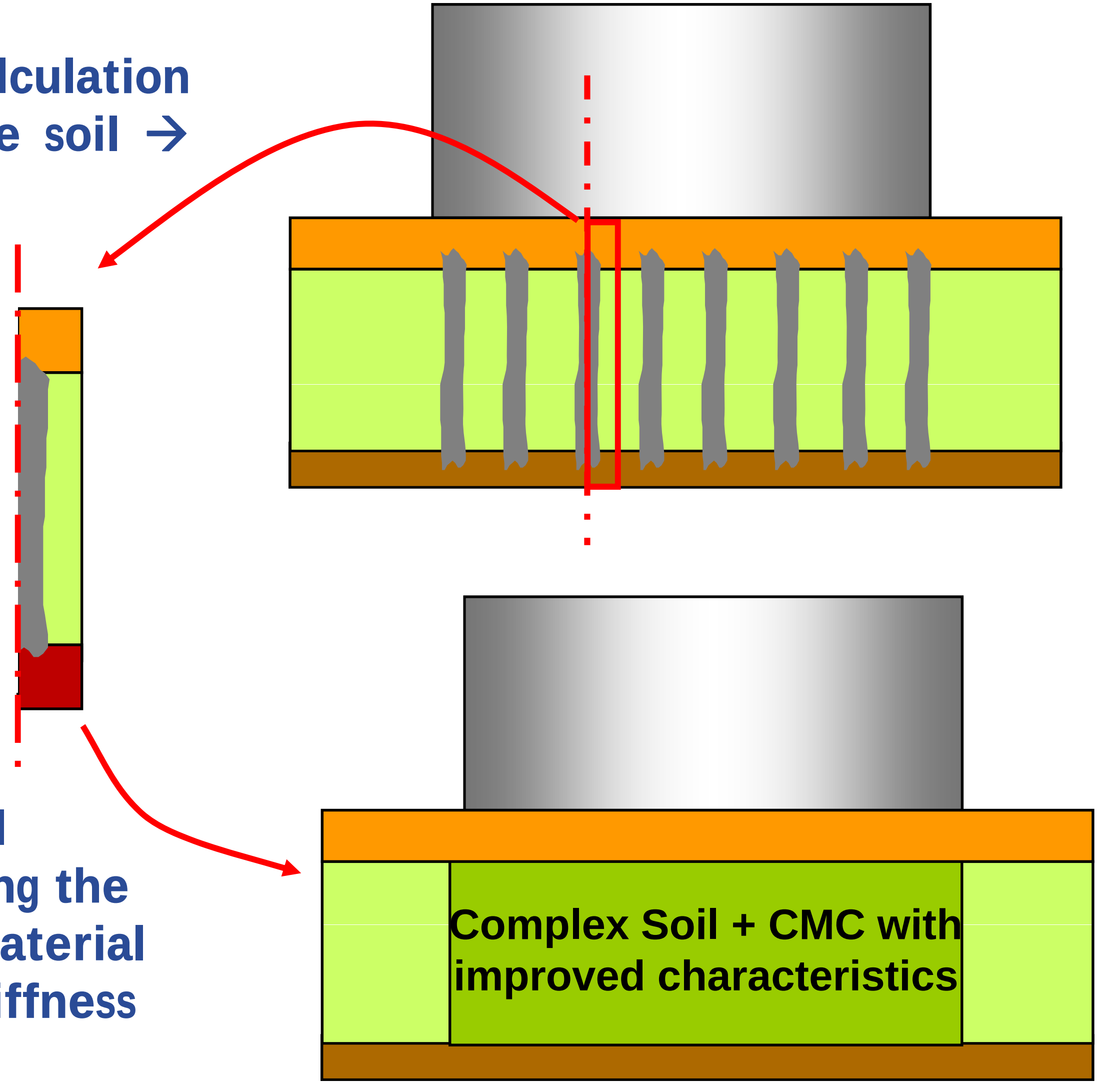
Equilibrium between positive and negative friction. Neutral point appears

Stress in the column



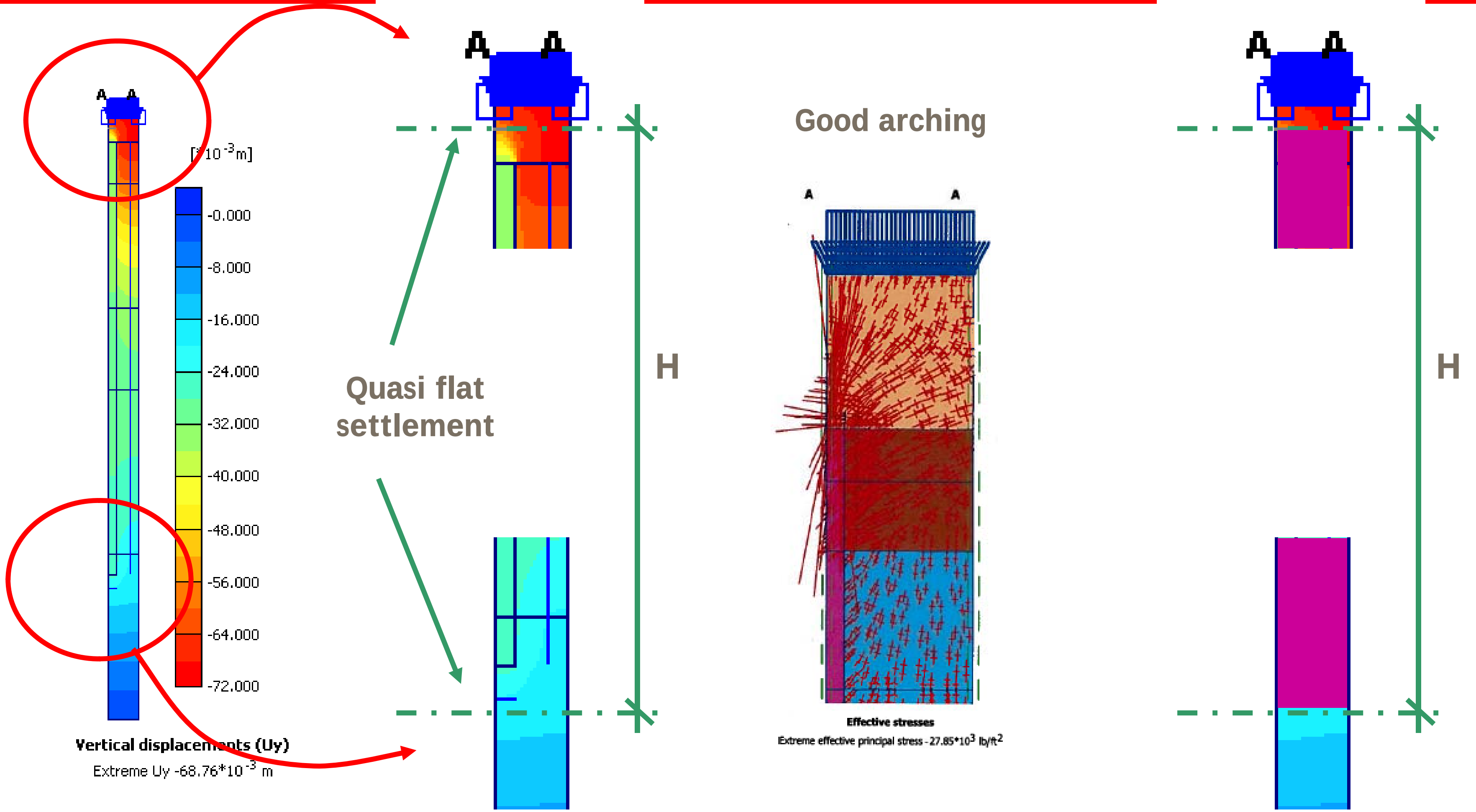
CMC Design - Principle

Axi-symmetric FEM calculation with one CMC and the soil → eq. Stiffness



Global axi-symmetrical calculation by modelling the improved ground by material having an improved stiffness

CMC Design - Global Modulus evaluation

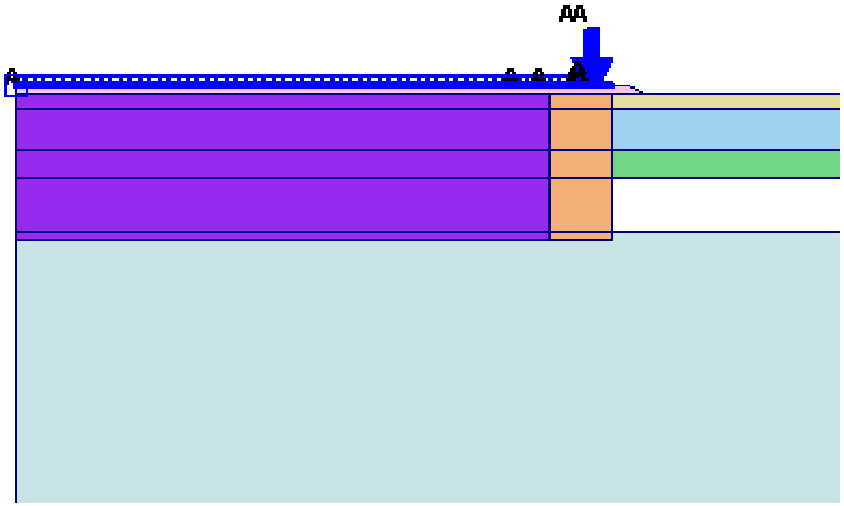


- **Checking:**
  - Quasi flat settlement
  - Good arching as shown by principal stress direction

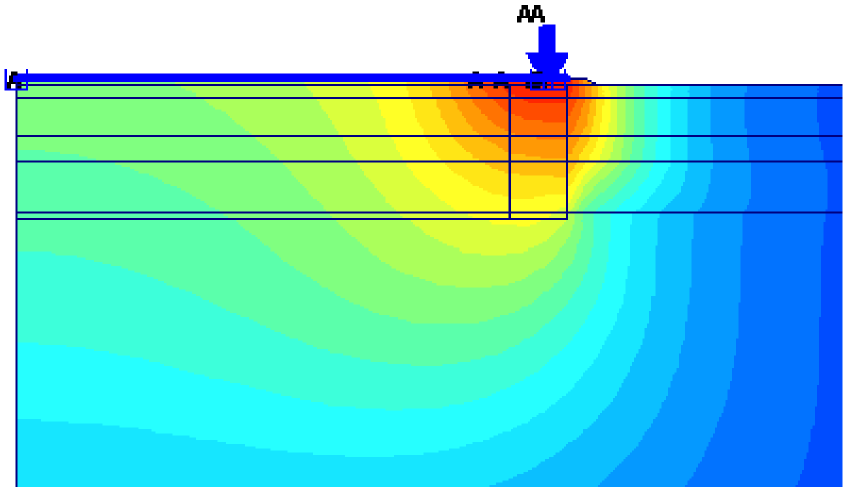
The structure « see » the complex [soil + CMC] as a uniform soil with improved parameters

CMC Design - Global Modulus Evaluation

Global axi-symmetric model



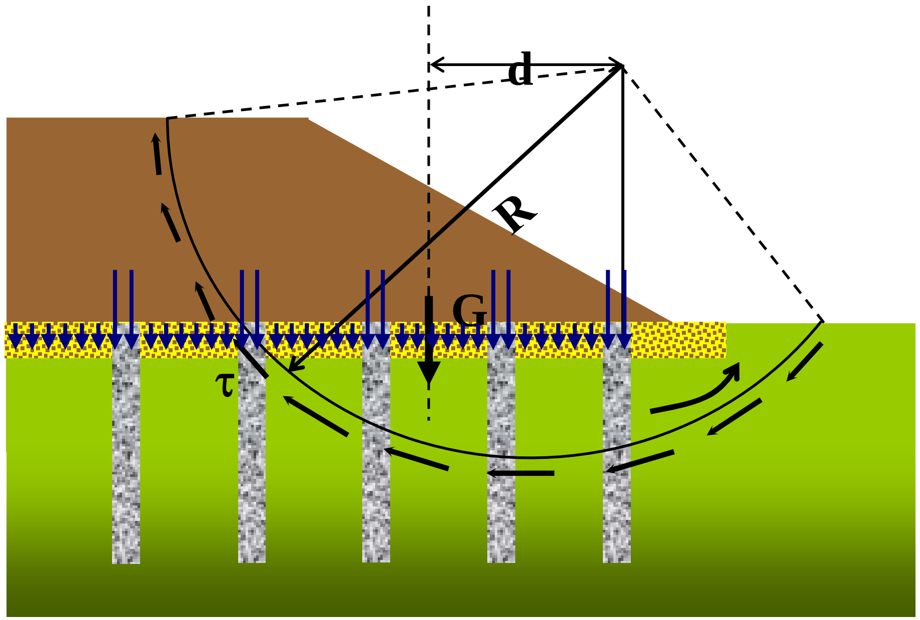
Global behaviour

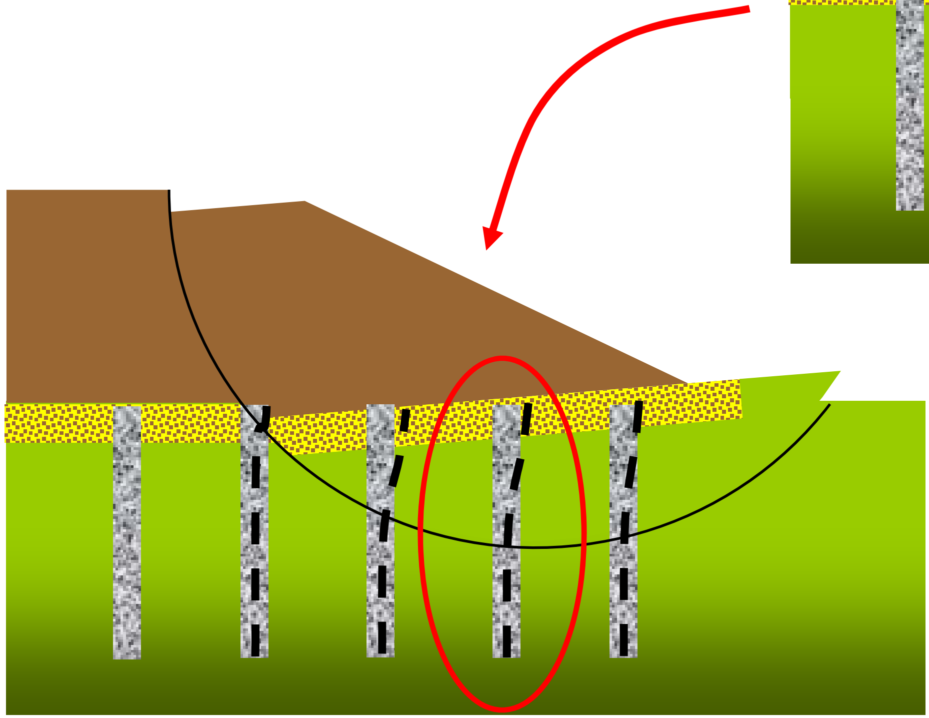


→ **Checking global settlement (total and differential)**

CMC Design - Specific case of non vertical loading

- **Main Issue:**
  - Momentum due to embankment,
  - Non reinforced inclusion

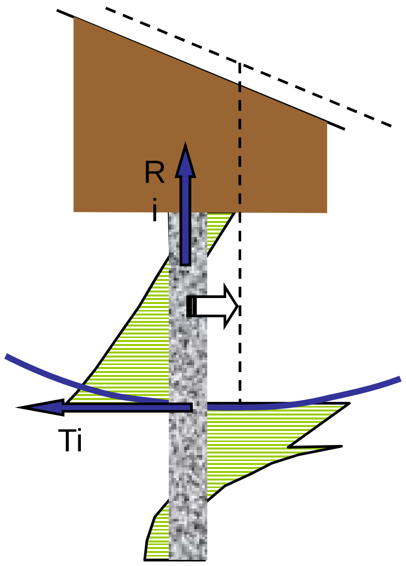


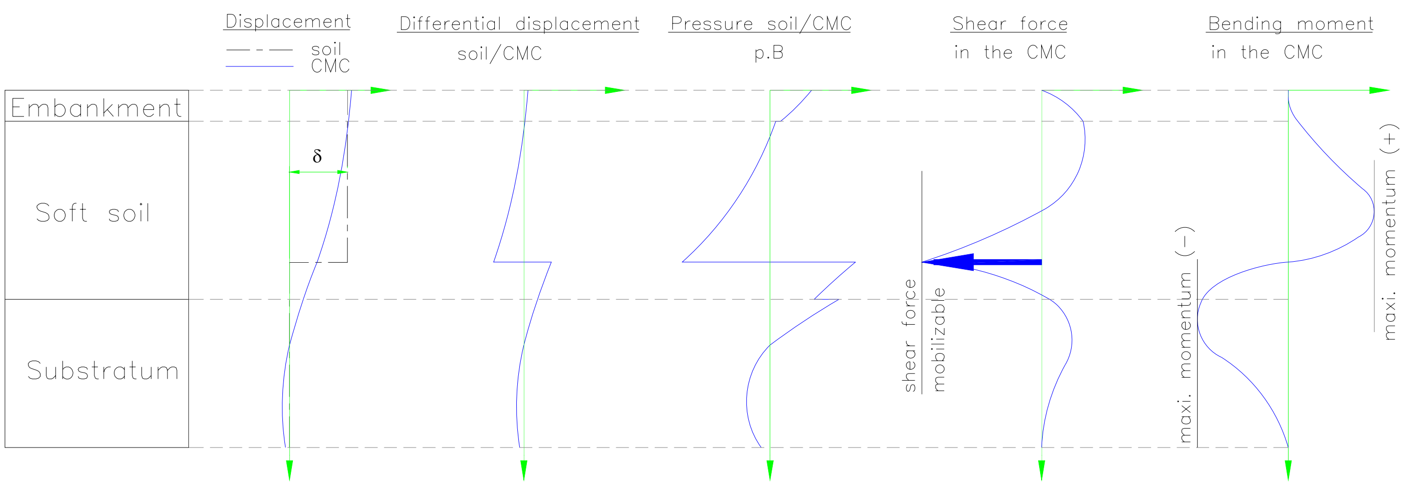


CMC Design - Specific case of non vertical loading

- **Calculation principle**

1. Estimation of the vertical stress in the column (% of the embankment load)
2. Thus maximum momentum so that $M / N \leq D / 8$ (no traction in the mortar)
3. Thus maximum shear force taken by the inclusion (similar to a pile to which a displacement is applied)
4. Modelling of the CMC as nails working in compression + imposed shear force under Talren software (or equivalent)

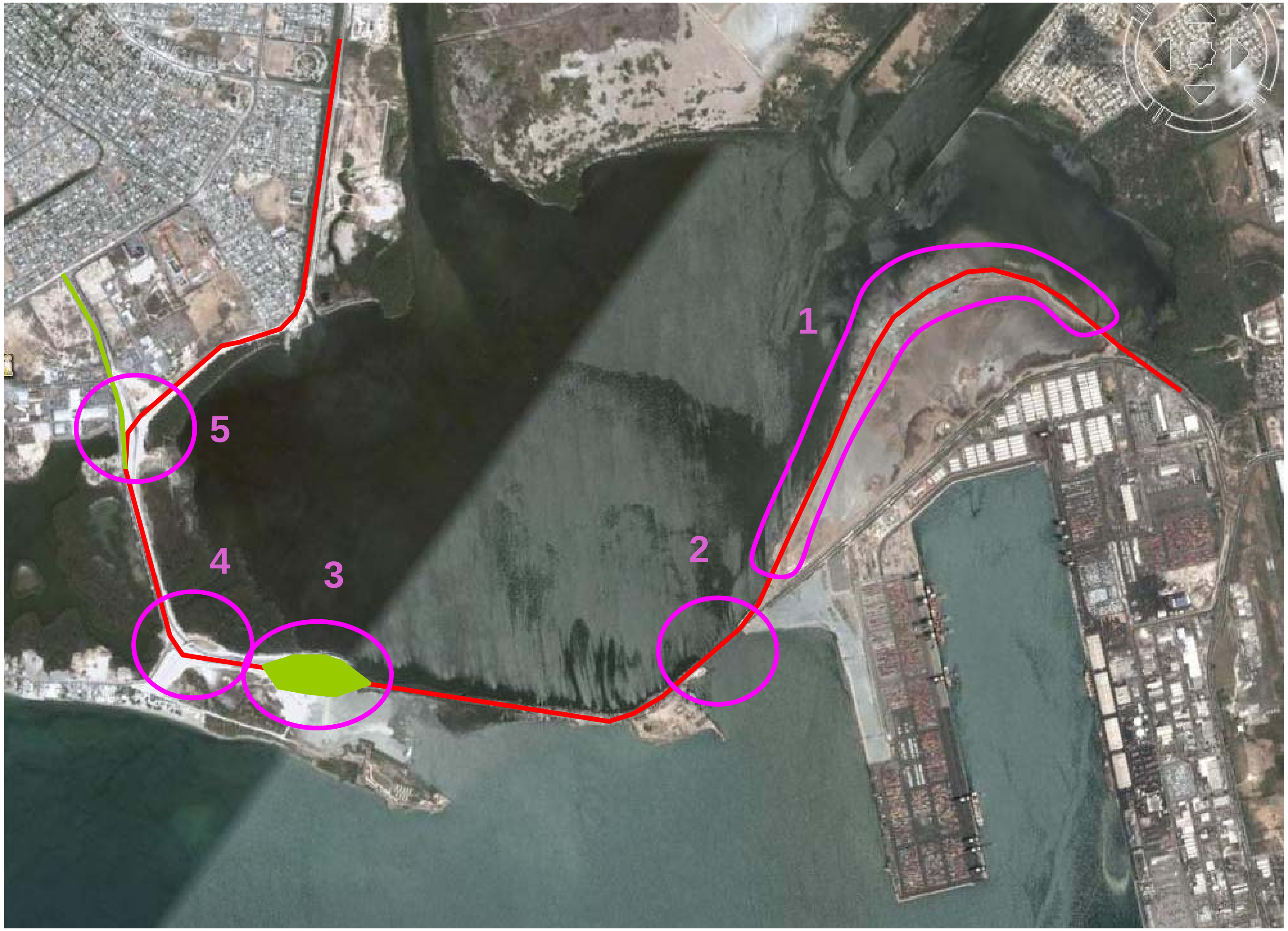




CMC Design - Benefits for the structure

- **Structure shall be designed as if soil was of good quality**
  - Specialist contractor provides structural designer with bearing capacity, k, etc…
- **No connection between foundation and structure**
  - Structure is less complex to be designed,
  - No stiff connection, thus no increase in seismic analysis,
  - Structure very simple to be built: footings and slab on grade, no pile cap, thus benefit in terms of cost and speed of execution

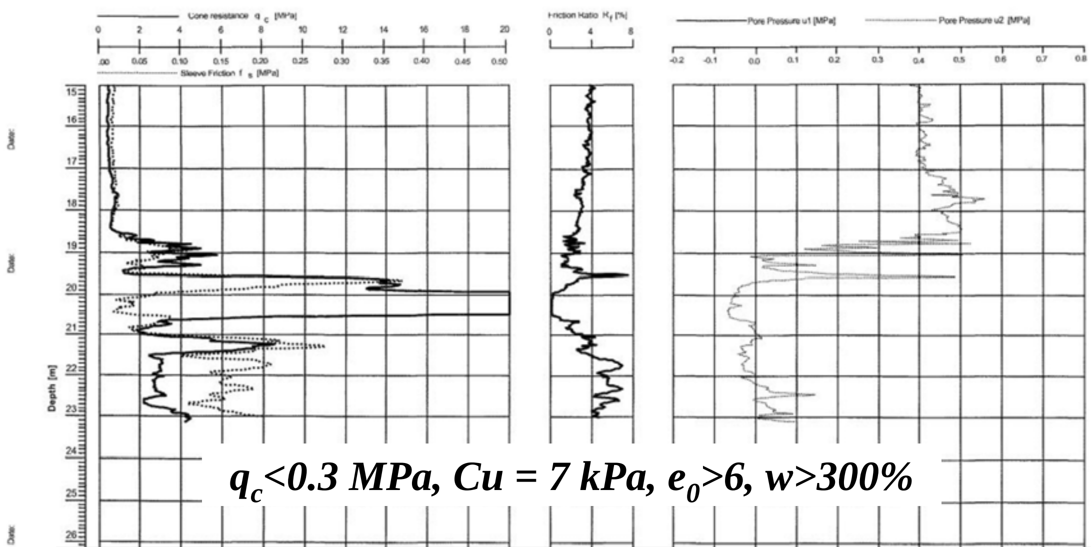
- **Aerial view**



1. **New Port Alignment**
2. **Hunt's Bay Bridge**
3. **Toll Plaza**
4. **Fort Augusta Interchange**
5. **Dawkins Drive Interchange**

CMC - Reference: H2K

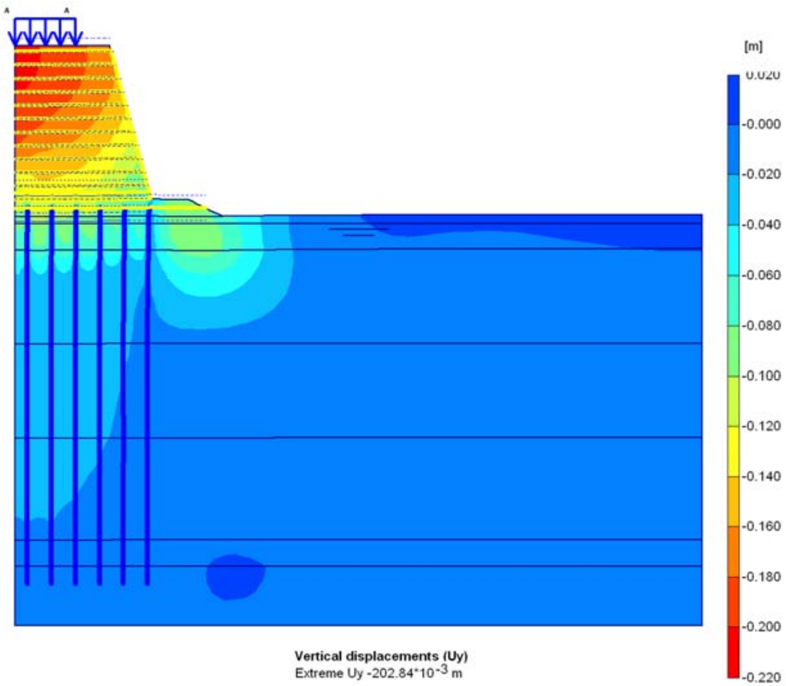
- **Soil Conditions and Specs**

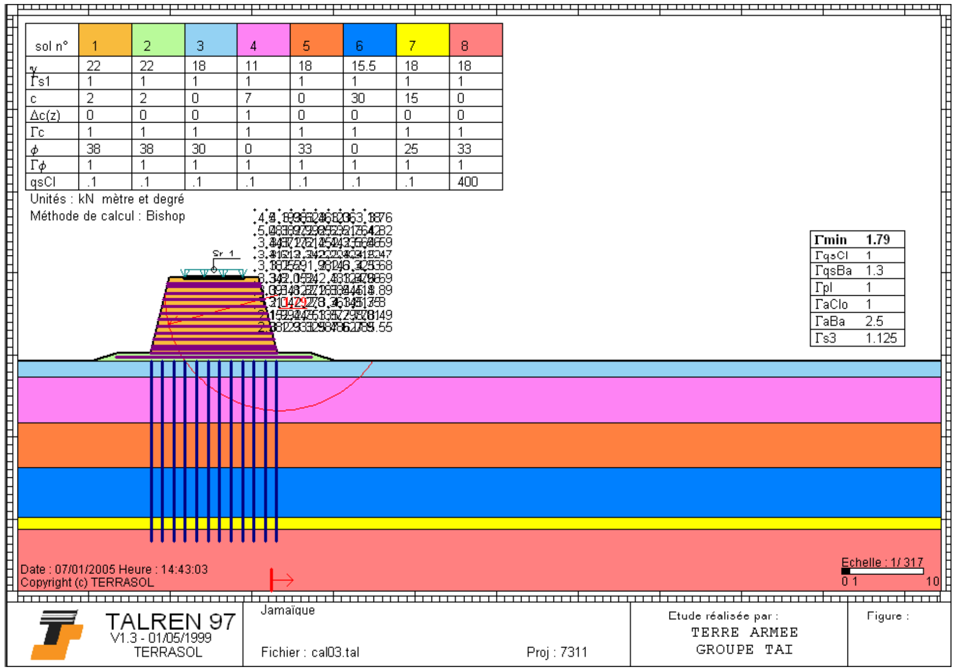


q_c<0.3 MPa, Cu = 7 kPa, e_0>6, w>300%

- Residual settlement after road opening to traffic: 200 mm over 35 years
- Static factor of safety against slope failure: 1.3 in long term conditions

- **Design of Interchanges: Deep CMC + wrap around embankments**





CMC - Reference: H2K - CMC execution

CMC - Reference: H2K - Wrap around

CMC - Reference: H2K - Other sections

- **PVD + surcharge while road in use**

CMC - Reference: Vung Tau Shipyard

- Shipyard over an area of 37,200 m²

- Design criteria
  - 5t/m² under the building imprint (24,800 m²) with maximum 300 mm settlement /10 years
  - For outside areas: possibility to have a 200 t crane moving anywhere, with full charge.

- Soil Conditions
  - Loose fine sand backfill 2.5 to 4.5 m thick,
  - 10 to 14 m very soft clay,
  - Stiffer clay for 6 to 13 m
  - Elevation to be raised by ~ 1 m.

- Other data
  - Client: EZRA group (Singapore)
  - Consultant: ATC (Singapore)

CMC - Reference: Vung Tau Shipyard

- **Concept**
  - Initial treatment aiming at reaching OCR = 1 under backfill @ EL + 2.4: Vertical Drain + surcharge,
  - Buildings: CMC diam. 360 mm to a depth of 20 to 22 m

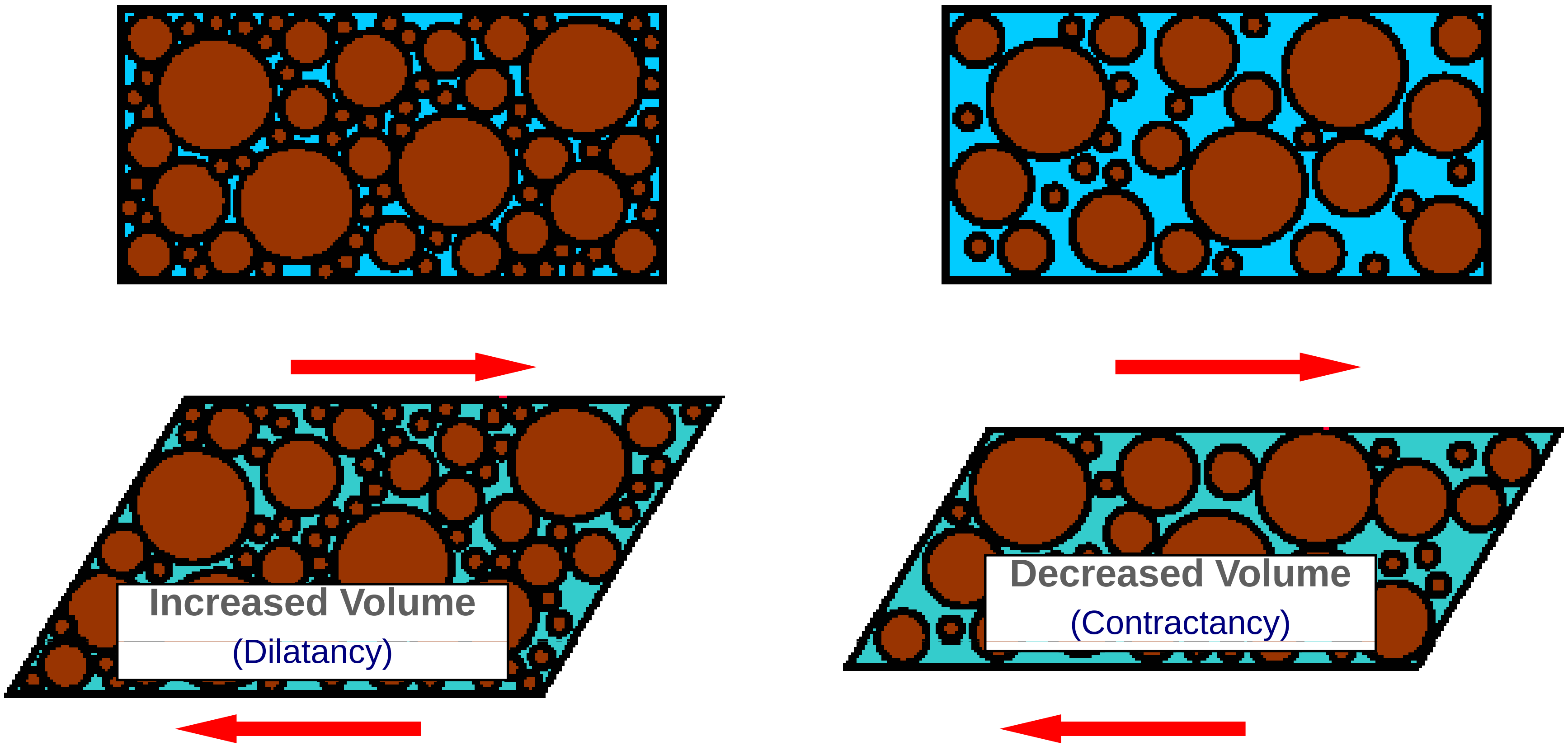
- **Execution**
  - Project started mid June 2008 with PVD + Surcharge,
  - CMC started mid September and was completed by December 2008
  - High speed of execution (about 700 lm/shift average).

CMC - Reference: Vung Tau Shipyard

New Developement - CMC Compaction - Principle

- **Depending on initial density, application of shear stresses on saturated soil can have different effects**

Initially in Dense state | **Initially in Loose state**



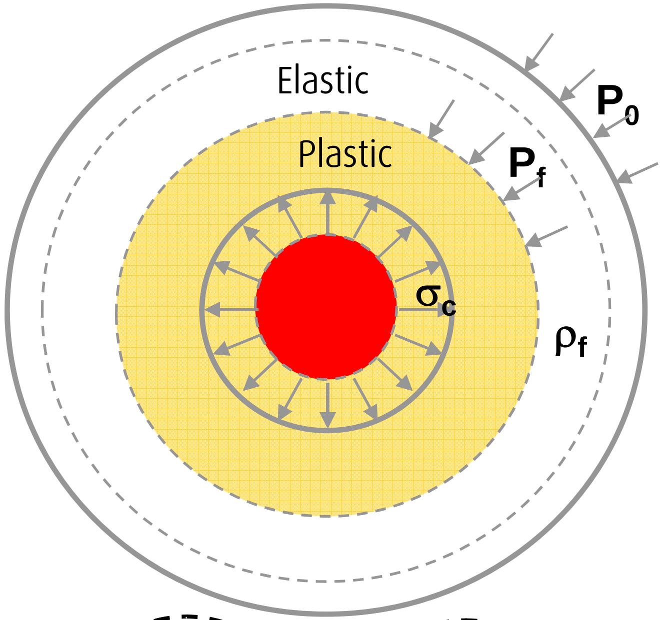
No pore pressure build up
=> No risk of liquefaction

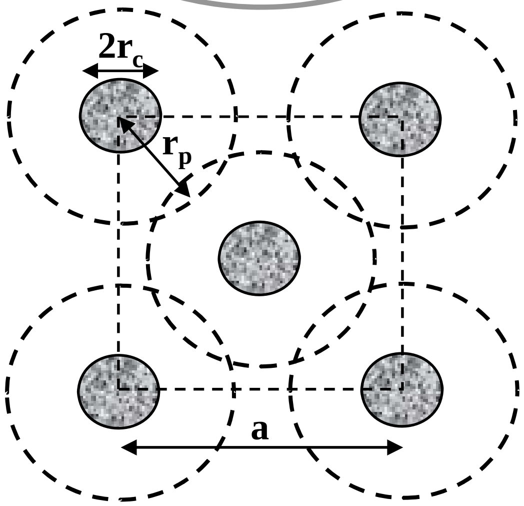
Pore pressure build up
=> Risk of liquefaction

New Developement - CMC Compaction - Principle

- **Aim of CMC to compact granular material to decrease liquefaction potential**

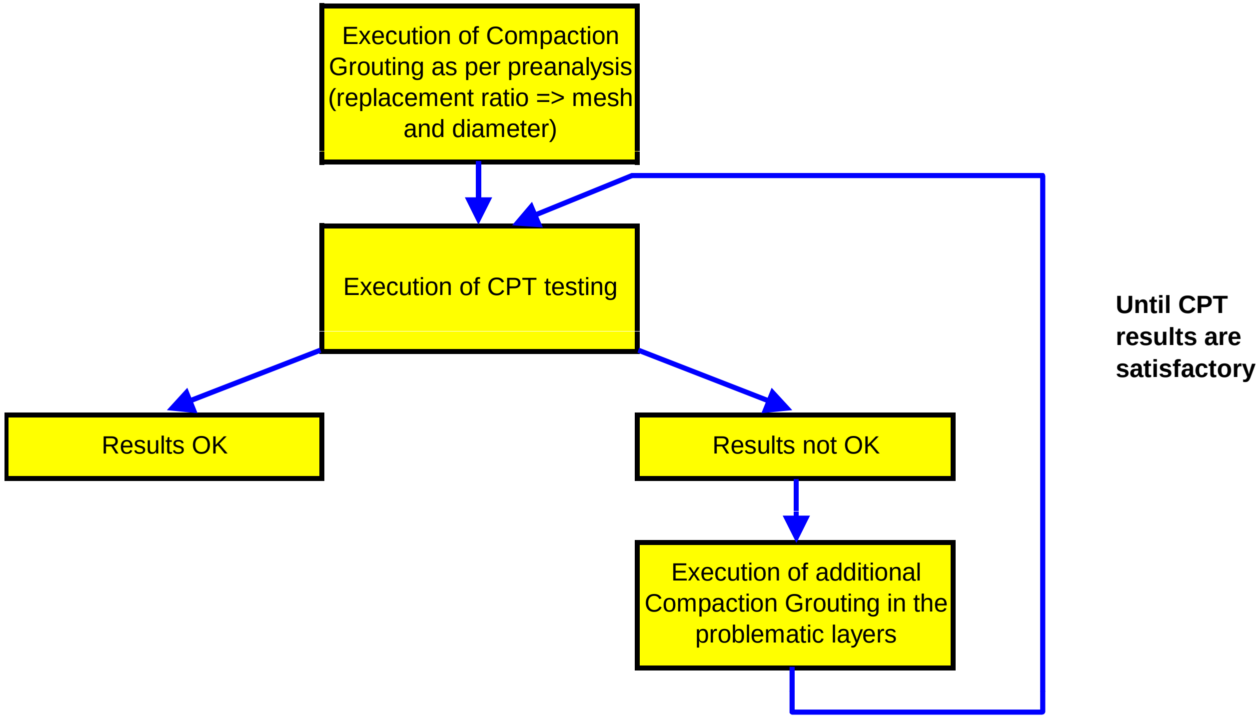
- **Method of densification**
  - Injected mortar used to displace and compact the soil around the injection point
  - Successive injection according to a regular grid induce a global compaction of the soil
  - Mesh and diameter designed so as to achieve a given replacement ratio

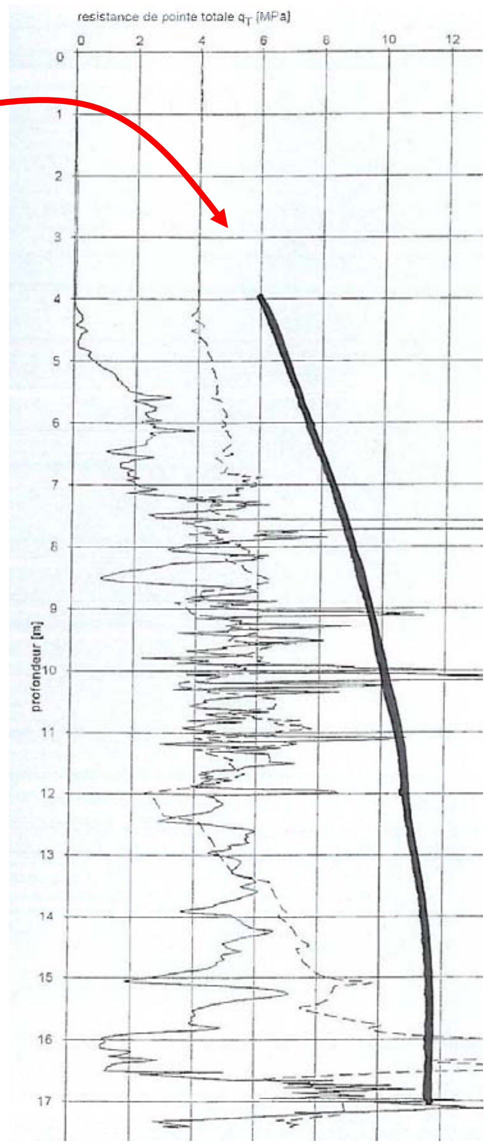




New Developement - CMC Compaction - Design

- **Principle: Execution and testing procedure**
  - Seismic parameters (PGA, Magnitude) → q_c soil profile to be achieved (Seed and Idriss methodology)
  - Estimation of replacement ratio to achieve required q_c
  - Execution of Works and testing by CPT
  - Additional grouting if necessary





New Developement - CMC Compaction - Design

- **Method 1: based on Dr**
  - $q_c \rightarrow D_r$ (Relative Density)
  - $D_r \rightarrow e \rightarrow$ Replacement ratio
  - Problem associated:
    - e_{min} & e_{max} values difficult to know
    - usually pessimistic

$$D_r = \frac{1}{C_2} \cdot \ln\left(\frac{q_c}{C_0 \cdot \sigma_m'^{\,C_1}}\right)$$

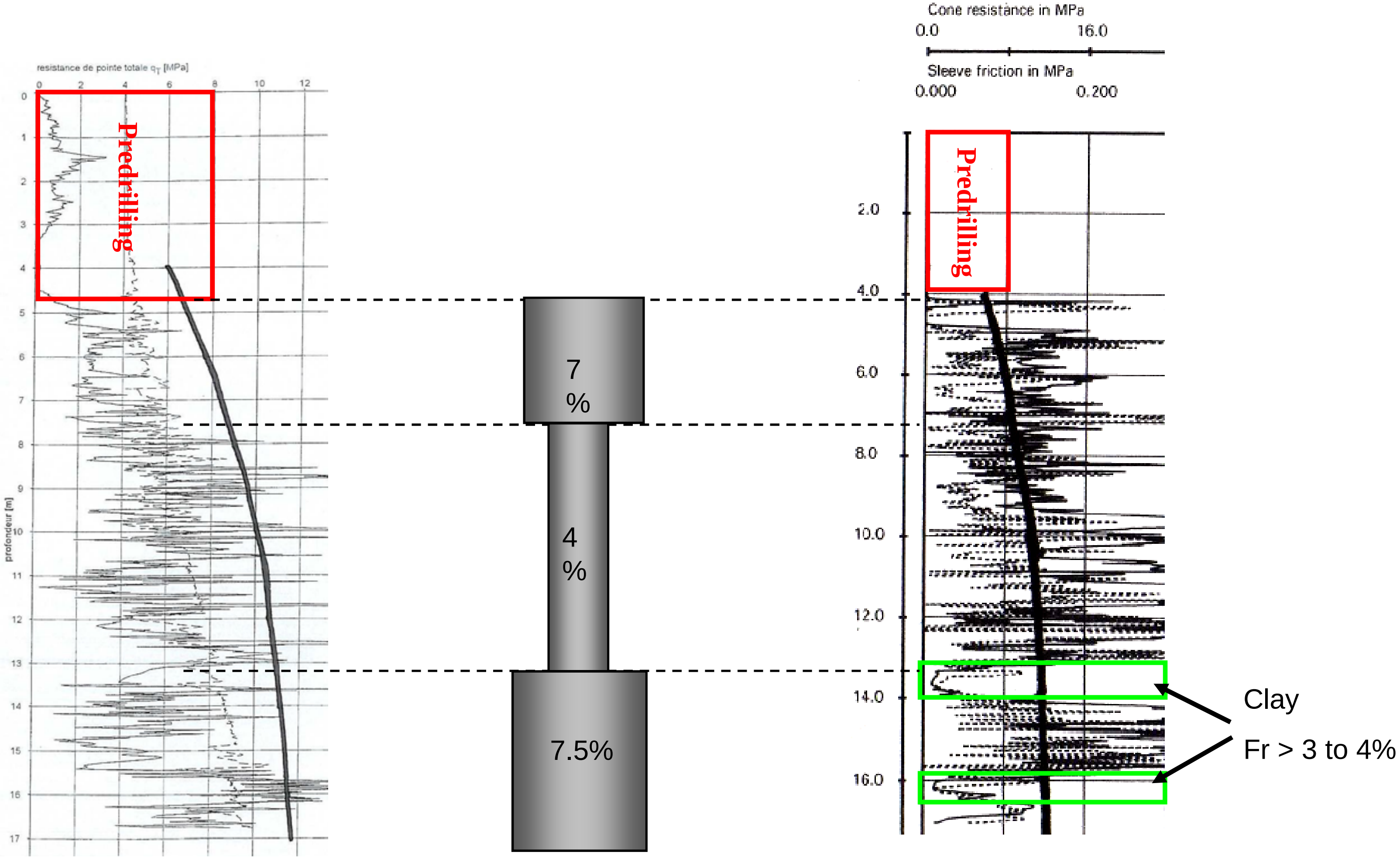
$$e = e_{\max} - D_r.(e_{\max} - e_{\min})$$

- **Method 2: based on D60 know how**
  - Based on experience, Menard defined an improvement ratio for each type of soil
  - Usually more accurate

Repl. ratio	Improvement ratio		
	SAND	SILT	CLAY
1%	1.3	1.2	1.1
2%	1.5	1.4	1.2
4%	2.0	1.6	1.3

→ **For pre-design, both analysis are conducted, then zone test area**

New Developement - CMC Compaction - Backanalysis



Before treatment

q_c = 3 to 5 MPa

After treatment

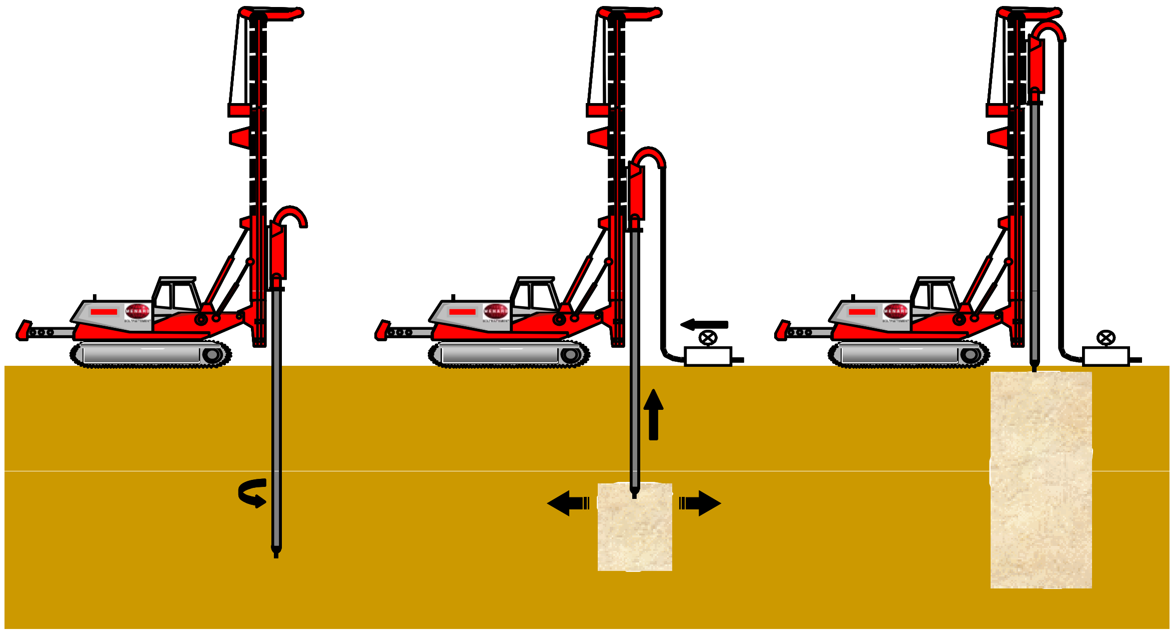
q_c = 10 to 15 MPa

New Developement - CMC Compaction - Execution

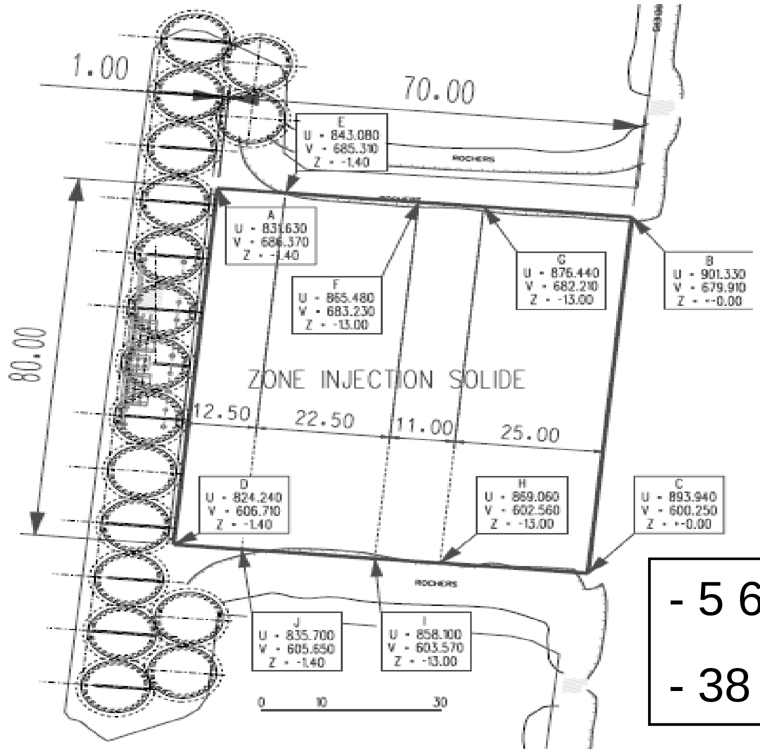
- **Same type of equipment as for CMC**
  - **Soil displacement rig and Pump,**

- **Key points**
  - **Quality of grout (grain size distribution, workability, consistency)**
  - **Injection speed and successive phases**

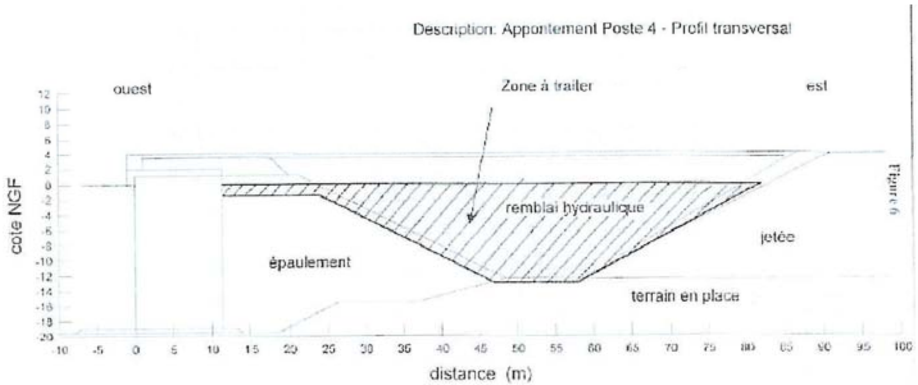
- **Final Testing = CPT**

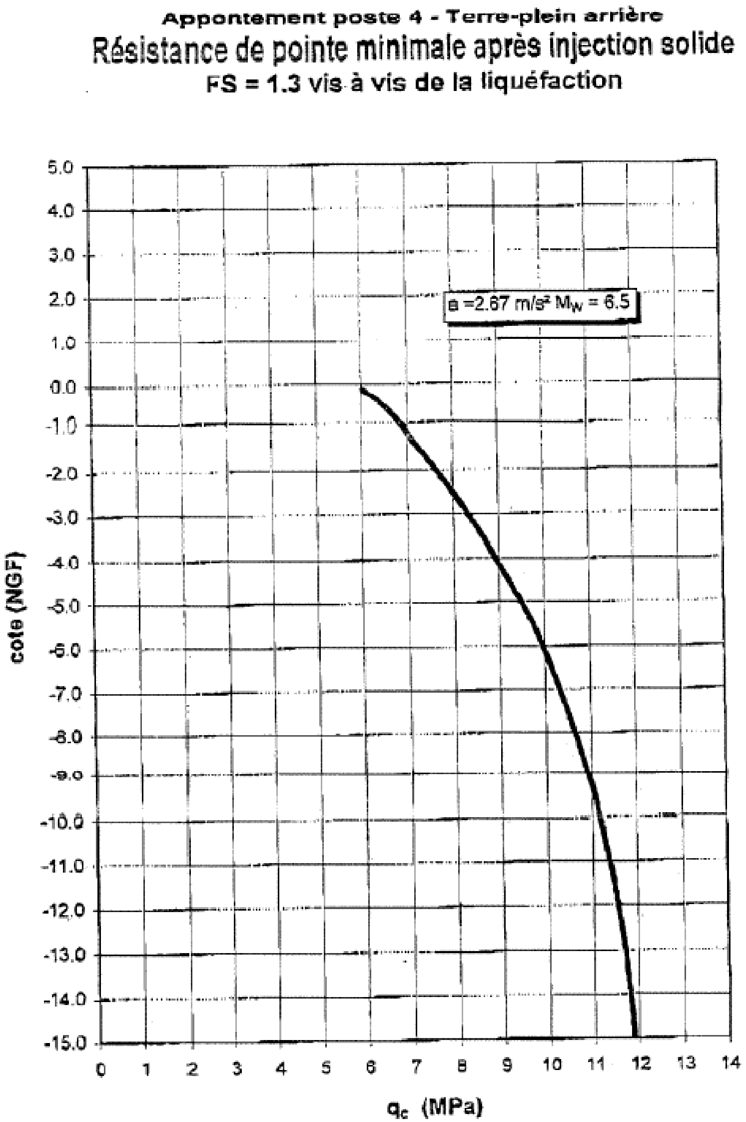


New Developement - CMC Compaction - Fos LNG Terminal



- 5 600m²
- 38 000m³





New Developement - CMC Compaction - Fos LNG Terminal

CMC - Typical Application






Warehouses **Tanks** **Roads**

Thank You

menard