BORED MICROPILES

FRENCH PRACTICE

MICROPILES

- Definition
- Construction principles (type of micropile)
- Grouting effect
- Capacity (structural and geotechnical)
- Load test
- Connection considerations
- Mauritius power plant

MICROPILES - DEFINITION -

Two documents are used in France DTU 13 - 2 (private market) **And Fascicule N° 62** (public market).
The next step will be the national document for application of the Eurocode 7

Up to now, According to these 2 French documents
Micropile are bored piles with diameter ≤ 250 mm with:

Drilling: with simultaneous or differed grout or mortar filling and generally introduction of a steel reinforcement (tube, bar, ….)
Note: When the soil condition allows, we can change drilling method by: lancing, percussion drilling, driven piling …..

Grouting: done by gravity or under pressure

These documents (DTU 13 – 2 and Fascicule 62) defined 4 micropile types (Type I, II, III and IV) according to their execution method.

Note: For ***European code EN 14199*** *micropiles are:*
Drilled piles with diameter < than 300 mm
Drived piles with diameter < than 150 mm

BORED MICROPILES – CONSTRUCTION PRINCIPLES -

The different drilled micropile types defined by DTU 13.2 and Fascicule 62 are:

Drilled micropiles with casing but without reinforcement

- Gravity filling or filling under low pressure (type I)

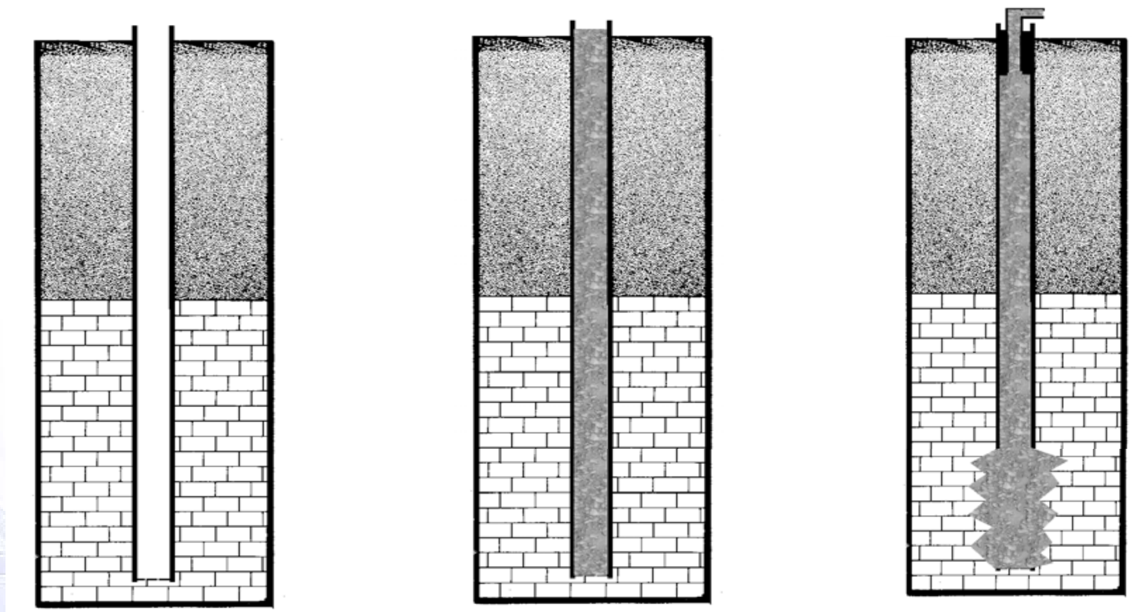
Drilled micropiles with reinforcement

- Gravity filing under low pressure (type II or type I if drilled with casing).
- Bonded using “tube à manchettes” under unitary global grouting (IGU) with P ≥ 1 Mpa (type III)
- Bonded using “tube à manchettes” under repetitive and selective grouting (IRS) with P ≥ 1 Mpa (type IV)

BORED MICROPILES – CONSTRUCTION PRINCIPLES -

(TYPE I of DTU 13-2 and Fascicule 62)

1 Drilling with casing
2 Then the casing is filled with grout or mortar
(+ eventually reinforcement can be installed)
3 And the casing is removed with grout or mortar under pressure

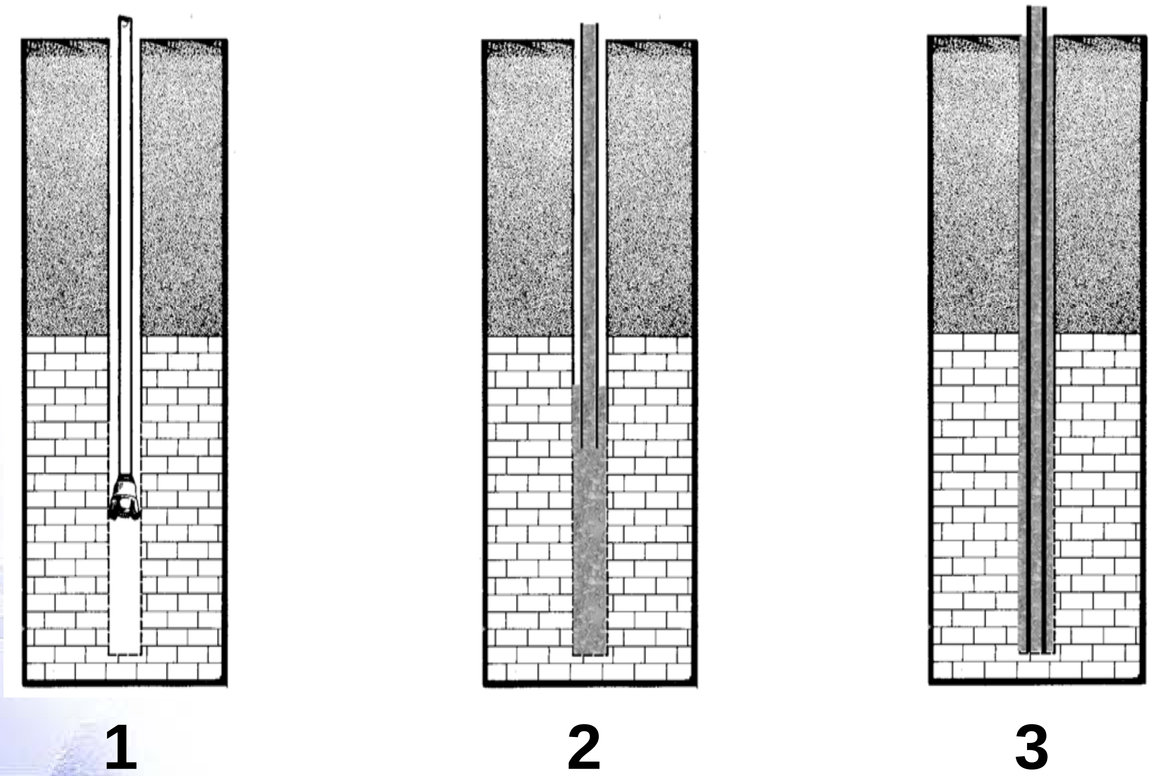


1 2 3

BORED MICROPILES – CONSTRUCTION PRINCIPLES -

(Type II of DTU 13 – 2 and Fascicule 62)

1 Drilling with drill tool and rod
2 Introduction of the reinforcement
3 Borehole filling with grout or mortar (from the bottom) by gravity or under low pressure



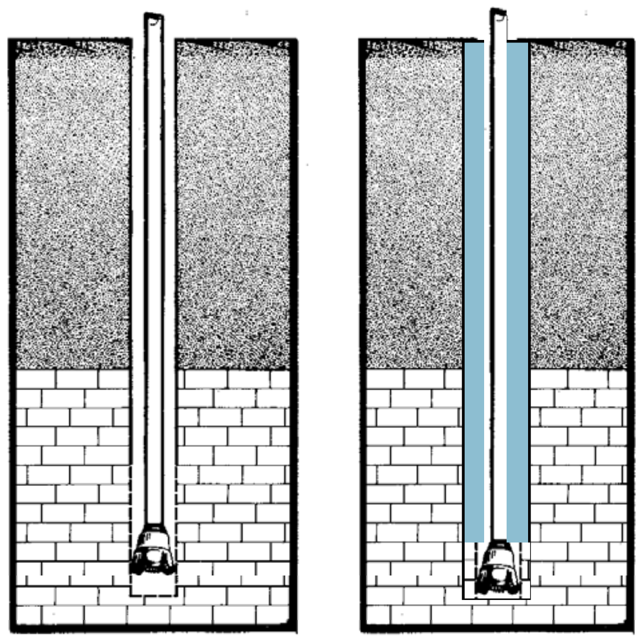
BORED MICROPILES – CONSTRUCTION PRINCIPLES -

(Type II for DTU 13 – 2 and Fascicule 62)

1 Drilling with the micropile tube itself

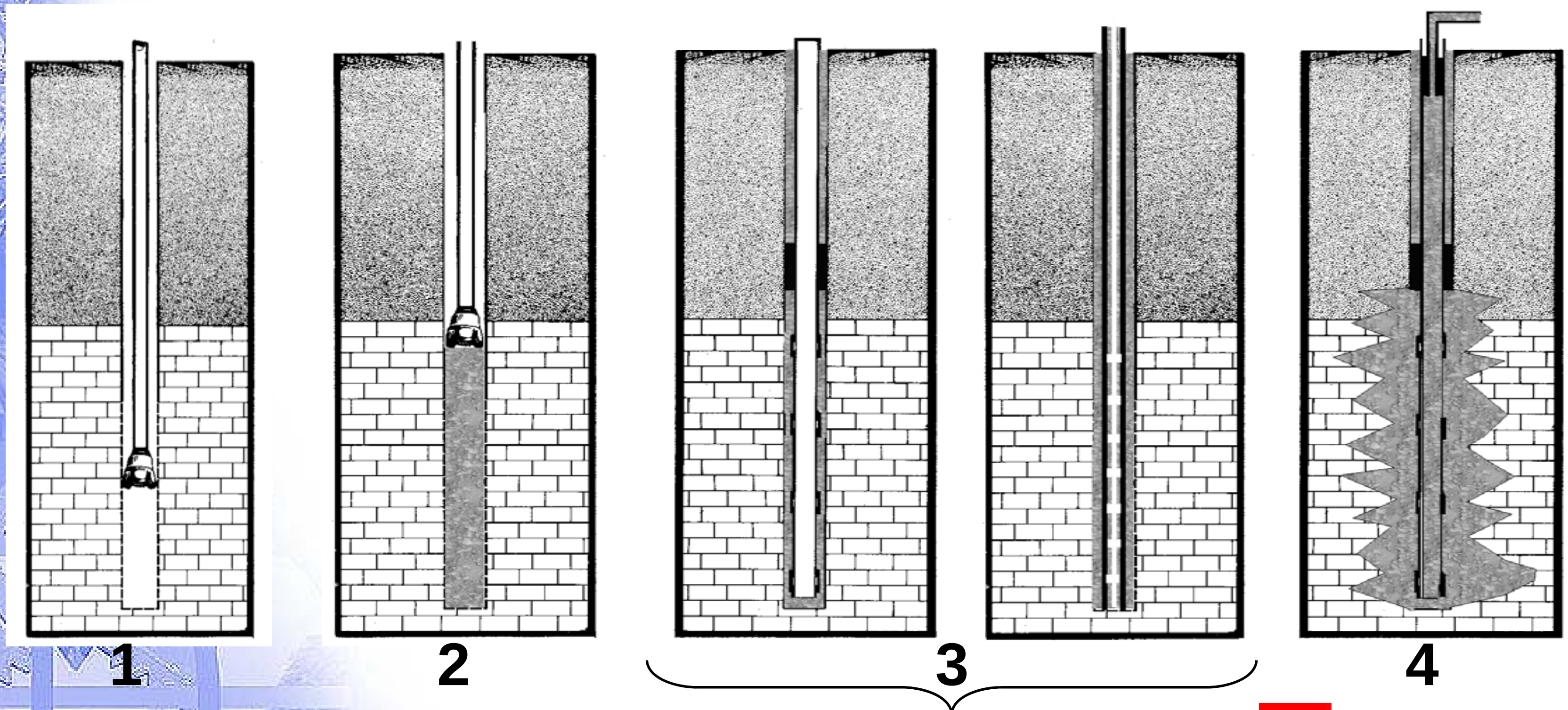
2 The grouting operation can be:

- Simultaneous (drilling with grout flush)
- Separate (substitution of the drilling flush by a grout or a mortar on completion of drilling)



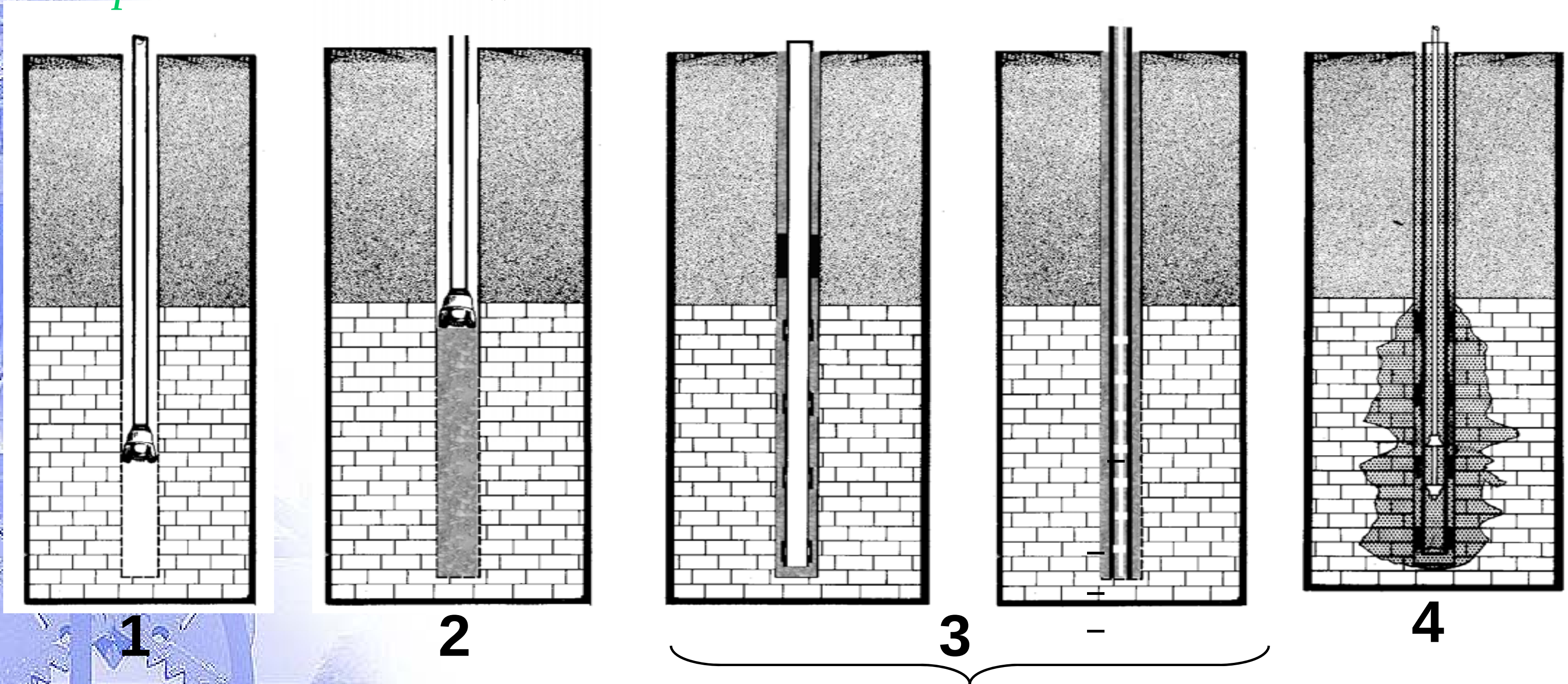
BORED MICROPILES – CONSTRUCTION PRINCIPLES -

1: Drilling with rod or (and) casing **(Type III DTU 13 – 2 and Fascicule 62)**
2: Placing the sleeve grout
3: Installation, in the primary grout, of the reinforcement equipped with injection sleeves (micropile tube with sleeves or, bars + tube à manchettes)
4: The micropile is then grouted by a single stage grouting (I.G.U. mode "***I****njection* ***G****lobale* ***U****nitaire*" with P≥ 1 Mpa)



BORED MICROPILES – CONSTRUCTION PRINCIPLES -

1 : Drilling with rod or (and) casing **(Type IV DTU 13 - 2 and Fascicule 62)**
2: Placing the primary grout
3: Installation, in the primary grout, of the reinforcement equiped with sleeve (micropile tube with sleeves or, bars + tube à manchettes)
4: The micropile is then grouted with grout or mortar by multi step grouting and multi stage grouting (repetitive and selective grouting: I.R.S. "***I**njection* ***R**epetitive* ***S**elective*" with > 1 MPa

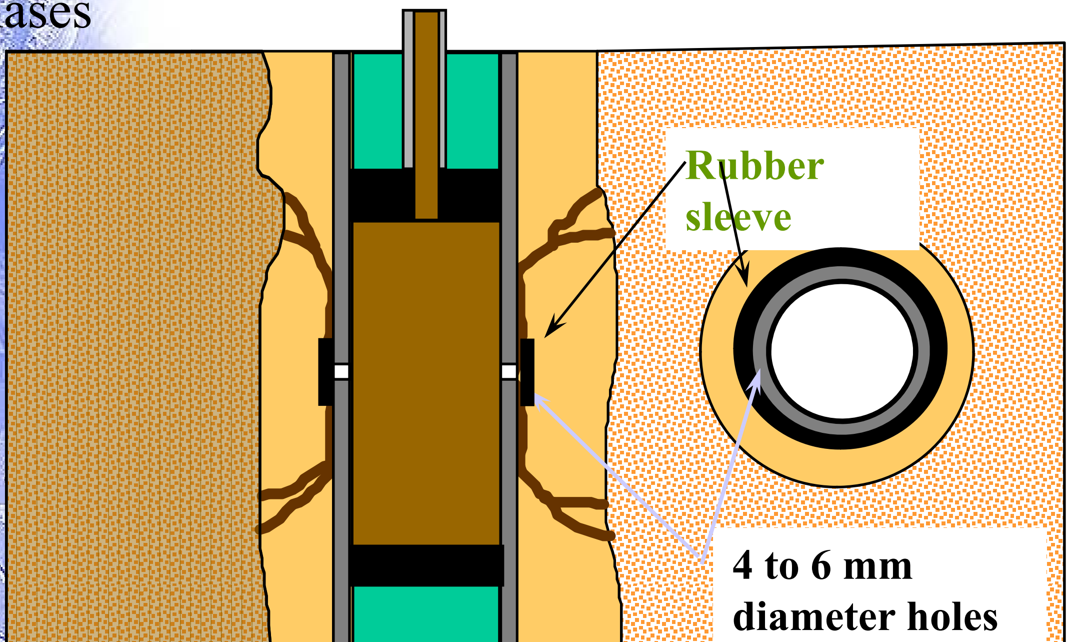


BORED MICROPILES - GROUTING EFFECT-

Grouting can be done in one step or by multi step and also by multi stage grouting

Multi step grouting: the micropile is grouted at different levels throughout manchettes (sleeve) or equivalent system.

Multi stage grouting: micropile is grouted via tube-à-machettes in different phases



Example of equipment for multi step and multi stage grouting IRS method

BORED MICROPILES - GROUTING EFFECT-

Section through a multi stage grouted body

The primary grout.

First phase of grouting.

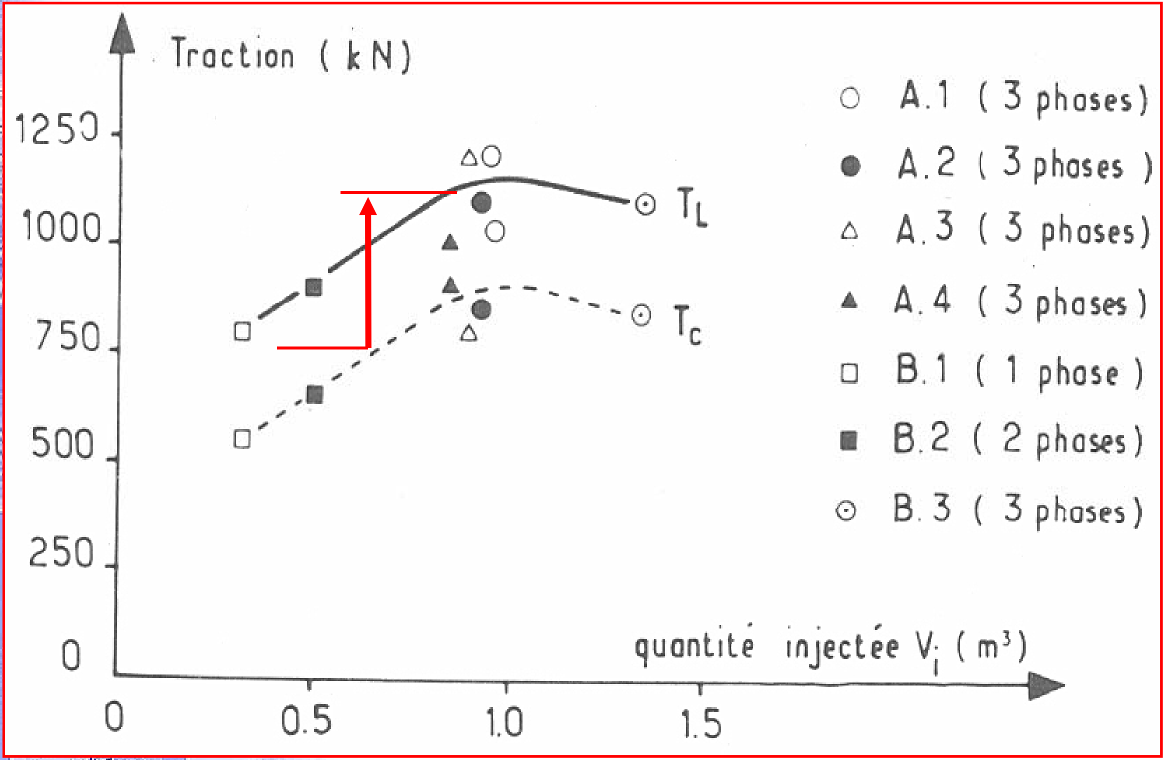
Second phase of grouting.

We see the effect of the IRS method in the enlargement of the grouted body

BORED MICROPILES - GROUTING EFFECT-

Effect of a multi step and multi stage grouting

This graph shows the increasing load capacity in Flanders clay achieved by IRS method grouting in a 140 mm diameter borehole of 6 m grouted length.



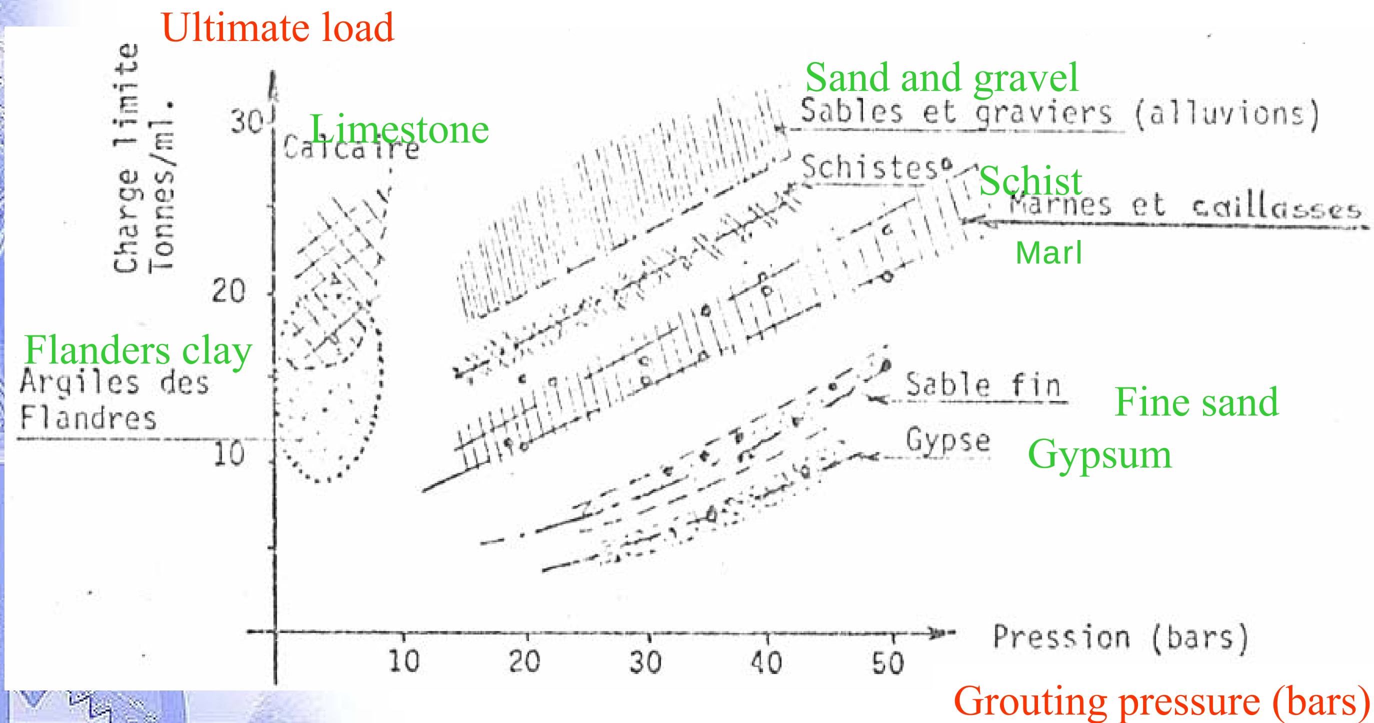
160 litres per meter grouted seems to be in this case the most efficient quantity. That means 60 ltr/m in each grouting stage (phase).

In Flanders clay the Pl value is 0.5 MPa and P(inj) ~ 0.5 MPa

BORED MICROPILES - GROUTING EFFECT-

Effect of the pressure grouting on IRS method

Influence of the grouting pressure on tension load capacity for grouted body of 140 mm initial diameter after multi step and multi stage grouting under pressure (IRS method).



BORED MICROPILES - CAPACITY -

For calculation of bored micropile we consider two types of capacity.

Structural capacity:

This capacity is directly connected to the reinforcement characteristics.

Geotechnical capacity:

For micropiles, only the skin friction is taken into account.

This capacity, for IGU & IRS grouted micropiles, is mainly based on analogy with results obtained for grouted anchors.

The methods of calculation of these value are actually given in the two documents, DTU 13.2 and Fascicule 62.

BORED MICROPILES - CAPACITY -

STRUCTURAL CAPACITY (with DTU 13 – 2)

MICROPILE TYPE 1 (no reinforcement)

- Calculation on basis of E.L.S load cases (Etat Limite de Service) = SLS (Serviceability Limit State)

  Uniform compressive strength of mortar → $\sigma'_c \leq 8$ MPa

MICROPILE TYPES 2, 3 and 4

- Strength calculation:

  Only the steel area is considered (reduced area is taken into account if there is corrosion risk or other considerations)

  - $\sigma_{ELS} \leq 0.5\ \sigma_{yield\ value}$
  - $\sigma_{ELU} \leq 0.75\ \sigma_{yield\ value}$

BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY (with DTU 13 – 2)

For this capacity we determine the ultimate skin friction Q_s (failure)

Such as: $Q_s = p \int h_i \, . \, q_{si}$

With: p = micropile equivalent circumference

(type I et II : p = drilling circumference)

(type III : p = drilling circumference x 1,2)

(type IV : p = drilling circumference x 1,5)

h_i = thickness of the soil layer « i »

q_{si} = ultimate skin friction qs of the soil layer « i »

The q_{si} values are tabulated in DTU annexes with reference to static penetrometer, dynamic penetrometer, SPT or pressuremeter.

In France, the most commonly used are the q_{si} values corresponding to the following pressuremeter values:

BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY (with DTU 13 – 2)

The choice of curve for q_{si} determination is based on pressuremeter information

For each type of micropile, the q_{si} value is obtained from a graph in relation to the type of soil and its pressuremeter value. (the selection of the graph is given by this summary table)

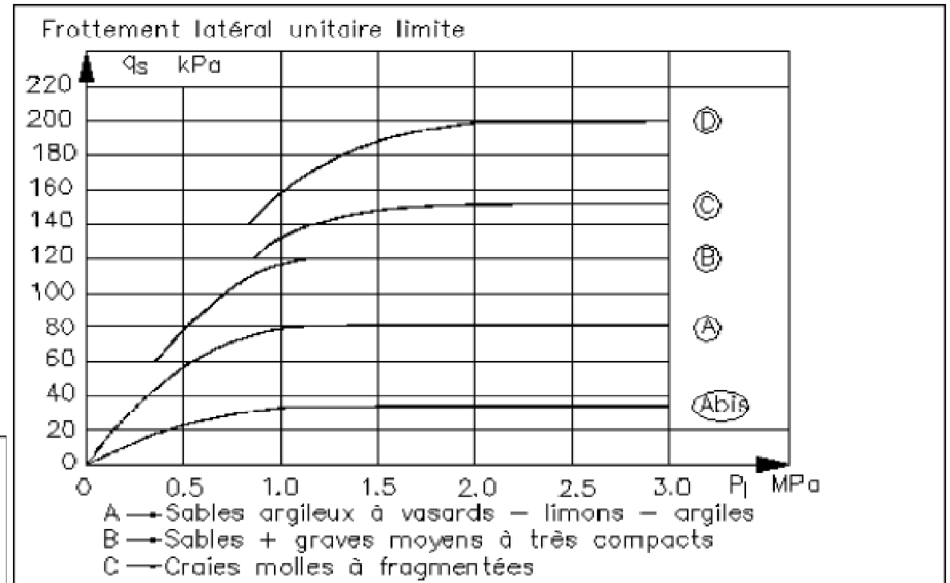
Type of soil	Limite Pressure Pl (Mpa)	SPT value	Type I	Type II	Type III	Type IV
Soft clay, lose silt and sand, soft chalk	0 to 0.7	0 to 17 (sand)		A bis	A	-
stiff clay and silt	1.2 to 2.0	24 to 40		(A) or A bis	A	D
very stiff or hard clay	> 2.0	> 40		(A) or A bis	A	D
medium dense to dense sand and gravel	1.0 to 2.0	30 to 50		(B) or A	B	≥ D
Very dense sand and gravel	> 2.5	> 60		(C) or B	C	≥ D
Weathered to fractured chalk	> 1			(C) or B	C	≥ D
Marl or claystone	1.5 to 4			(E) or C	E	F
Hard marl	> 4.5			E	F	> F
Weathered rock	2.5 to 4			F	≥ F	> F
Fractured rock	> 4.5			F	≥ F	> F

Ex: in medium to dense sand for micropile type III, the curve "B" will be considered to gives the q_{si} value.

BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY (with DTU 13 – 2)

The choice of curve for q_{si} determination based on pressuremeter information

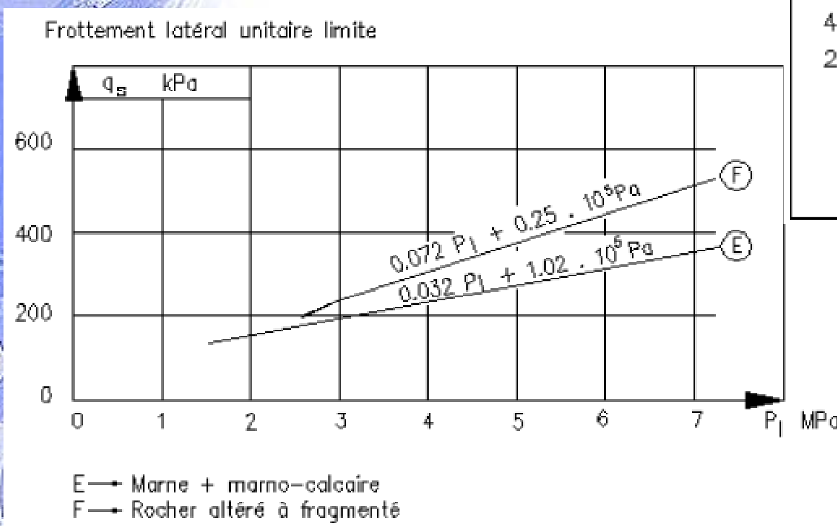


Curves showing q_{si} in relation with the limit pressure for given soil

Ex: curve "B" if

Pl = 0.5 Mpa → qsi = 80 KPa

Pl = 2 MPa → qsi = 120 KPa



A → Clayey sand, silt or clay

B → Dense to very dense sand or gravel

C → Soft to fragmented chalk

E → Marl or clay stone

F → Weathered to fractured rock

BORED MICROPILES - CAPACITY -

STRUCTURAL CAPACITY (with FASCICULE 62)

Calculation strength: (micropile types II, III et IV - type I not allowed)

- Only the steel is taken into account with the total or reduced area according to the soil aggressivity and the corrosion effect on the steel section.
- For the different load case combinations, we calculate the following loads: Q_{ELS} (service limit state) and Q_{ELU} (ultimate limit state)

  and the ratio $k = Q_{ELU} / Q_{ELS}$

Then we verify for value Q_{ELU} that the strength:

$\sigma_{ELU} \leq 0.8 .\sigma_{e \text{ (Yield value)}}$ that means : $(\sigma_e / 1,25)$

The ratio « k » between Q_{ELU} and Q_{ELS} (mainly 1,35 to 1,4) allows us to calculate σ_{ELS}

We calculate the strength σ_{ELS}:

$\sigma_{ELS} = \sigma_{ELU} / k = (0,8\ \sigma_e) / k$

for example if k=1,4 -----> $\sigma_{ELS} = 0.57\ \sigma_{e \text{ (Yield value)}}$ (with a maximum of 0,6 σ_e)

BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY (with FASCICULE 62)

The unit skin friction q_s, can be derived from soil tests results using tables or charts (pressuremeter and penetrometer).

Then we calculate Q_{SU} (mobilisable ultimate skin friction load) and we calculate the value of the micropile characteristic load for a given soil.

These loads are: Ultimate load characteristic Q_U (compression) and Q_{TU} (tension)

Creep load characteristic Q_C (compression) and Q_{TC} (tension)

Such as:

$Q_U = Q_{TU} = Q_{SU}$

and

$Q_C = Q_{TC} = 0{,}7\ Q_{SU}$

With: $Q_{SU} = P.\int_0^h qs(z).dz$

Where P = micropile circumference

and q_s = Unitary skin friction

Finally we verify that the loads obtained according to the different load case combinations satisfy the following conditions:

Load combinations	Limit state	Design load
Fundamental	Ultimate (ELU=ULS)	$Q_{ELU} \leq Q_U/1{,}4$ that means Qsu / 1,40
Accidental	Ultimate (ELU=ULS)	$Q_{ELU} \leq Q_U/1{,}2$ that means Qsu / 1,20
Rare (characteristic)	Serviceability (ELS=SLS)	$Q_{ELS} \leq Q_C/1{,}1$ that means Qsu / 1,57
Quasi permanent	Serviceability (ELS=SLS)	$Q_{ELS} \leq Q_C/1{,}4$ that means Qsu / 2,00

BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY
Fascicule 62

qs determination

Soils classification for fascicule 62				
type of soil	category		Pressuremeter Pl (Mpa)	Penetrometer q_c (Mpa)
clay, silt	A	soft clay and silt	< 0.7	<3.0
	B	Stiff clay and silt	1.2 - 2.0	3.0 - 6.0
	C	Hard clay	>2.5	>6.0
Sand, gravel	A	loose	<0.5	<5.0
	B	dense	1.0 - 2.0	8.0 - 15.0
	C	very dense	>2.5	>20.0
Chalk	A	Soft	<0.7	<5.0
	B	Weathered	1.0 - 2.5	>5.0
	C	Hard	>3.0	-
Marl and claystone	A	Soft	1.5 - 4.0	-
	B	Hard	>4.5	-
Rock	A	Weathred	2.5 - 4.0	-
	B	Fractured	>4.5	-

Soil category from Fascicule 62 according to soil pressuremeter and penetrometer value

Micropile type	Drilling method	Clay, silt			sand, gravel			Chalk			Marl		Rock
		A	B	C	A	B	C	A	B	C	A	B	A or B
II	dry drilling	Q1		Q2	-	-	-	Q1	Q3	Q4	Q3	Q4	Q6
	Drilling with mud		Q1		Q1	Q2 - Q1*	Q3 - Q2*	Q1	Q3	Q4	Q3	Q4	Q6
	Drilling with casing (casing remouved)	Q1	Q1 - Q2**		Q1	Q2 - Q1*	Q3 - Q2*	Q1	Q2	Q3 - Q4**	Q3	Q4	-
III	Grouted under low pressure	Q1	Q2			Q3		Q2	Q3	Q4	Q5		-
IV	Grouted under higth pressure (IRS)	-	Q4	Q5	Q5		Q6	-	Q5	Q6	Q6		Q7***

(*) For higth length (more than 30 meters)

(**) Dry drilling

(***) With pregouting of the fractured rock and cavity filling

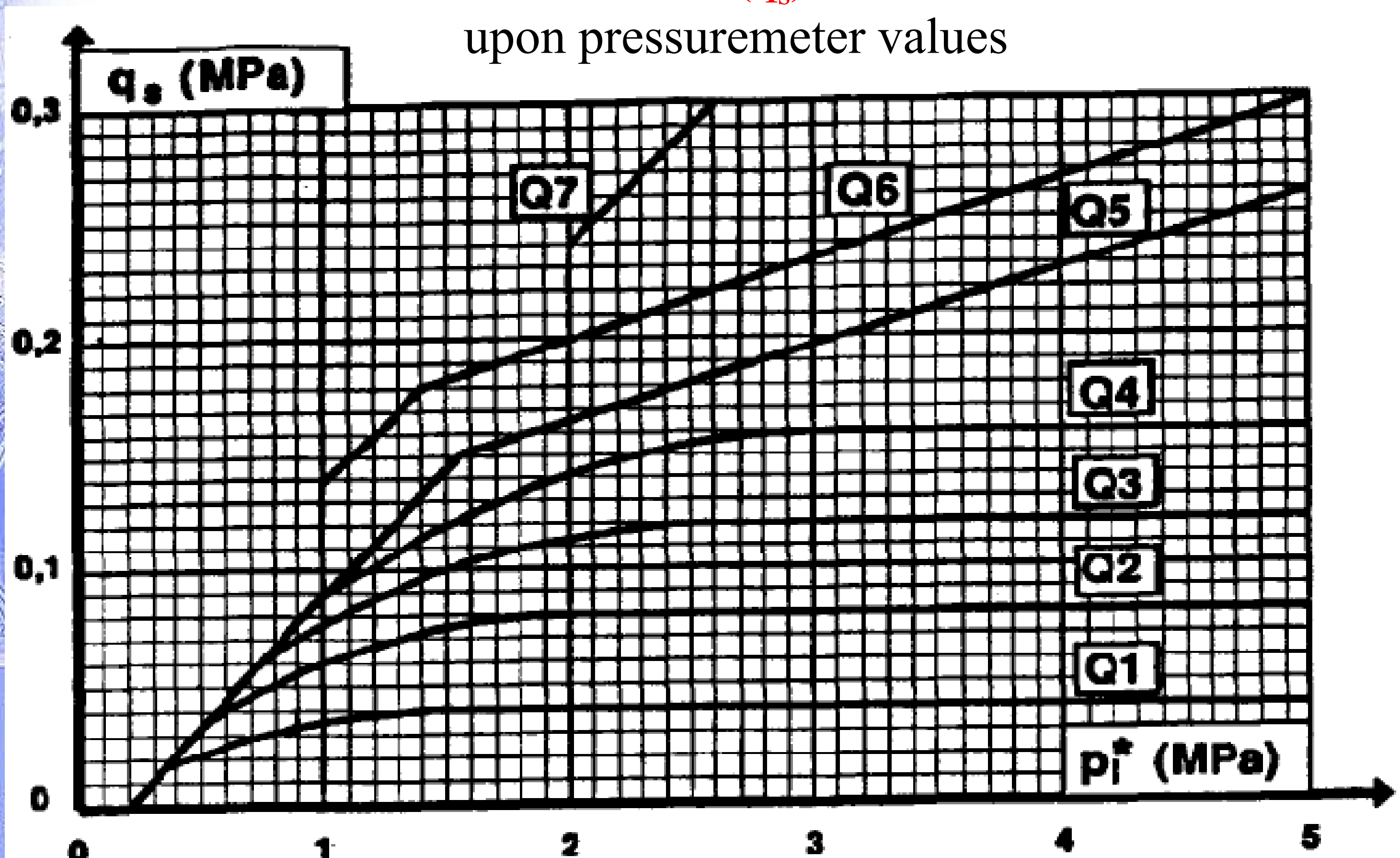
Choice of the curve for q_s determination

BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY (with FASCICULE 62)

Curves for skin friction (q_s) value determination

upon pressuremeter values



BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY (with FASCICULE 62)

In a same way, based on micropile tests (static load test), we determine for a given soil the « Q_i » values of the load characteristics in compression Q_u (failure) and Q_c (creep) or in tension Q_{TU} and Q_{TC}
For that, we amend the measured values by a coefficient which depends on the number of tests done.

(ex: $Q_i = Q_{measured} / 1,2$ if only one test load)

In this way we obtain the characteristic values Q_U (ultimate load characteristic) and Q_C (creep load characteristic)

Then we verify that the load obtained according to the different load case combinations satisfy to the following conditions:

Load combination	Limit state		Design load
Fundamental	Ultimate	(ELU =ULS)	$Q_{ELU} \leq Q_U/1,4$
Accidental	Ultimate	(ELU=ULS)	$Q_{ELU} \leq Q_U/1,2$
Rare	Serviceability	(ELS=SLS)	$Q_{ELS} \leq Q_C/1,1$
Quasi permanent	Serviceability	(ELS=SLS)	$Q_{ELS} \leq Q_C/1,4$

MICROPILES - LOAD TESTING -

STATIC LOAD TESTS (tests generally used in France)

- **Preliminary tests:**

  Designed to verify and refine the micropile design according to the following tests values:
  - Critical creep load
  - Ultimate load (failure)
  - Eventually q_{si} (if the micropile is instrumented)
- **Control test:**
  Designed to verify the working load conformity

DYNAMIC LOAD TESTS and INTEGRITY TESTS

(not commonly used in France)

Designed to determine generally the ultimate load

The European code EN 14199 requires careful attention regarding the difficulty of executing this test due to the small micropile diameter, and the fact that this test should generally be limited to the case where the results compared with static load test give a greater confidence.

MICROPILES - LOAD TESTING -

NUMBER OF TESTS

- **PRELIMINARY TESTS:**

No specific number of test are given by DTU 13.2 and Fascicule 62

The European code proposes a minimum of 2 tests when necessary (see project specifications)

- **CONTROL TEST:**

In compression:

1 test each 200 micropiles (DTU 13.2)

2 tests for the first 100 micropiles, then 1 test each 100 micropiles (EN 14199)

In tension:

1 test each 50 micropiles (DTU 13.2)

2 tests for the first 25 micropiles, then 1 test each 25 mocropiles (EN 14199)

MICROPILES - LOAD TESTING -

PRINCIPLE OF THE STATIC LOAD TEST

In this test, an axial load is applied to a micropile in steps up to a proof load. During each step the load is maintained constant during the time (30 to 60 minutes)

- **Static load test (to failure):**

  Failure load (Q_l ou Q_{tl}) estimated from geotechnical test

  Proof load test = Q_{tmax} = 1,5 Q_{tl} (for tension load test)
  1,3 Q_l (for compression load test)

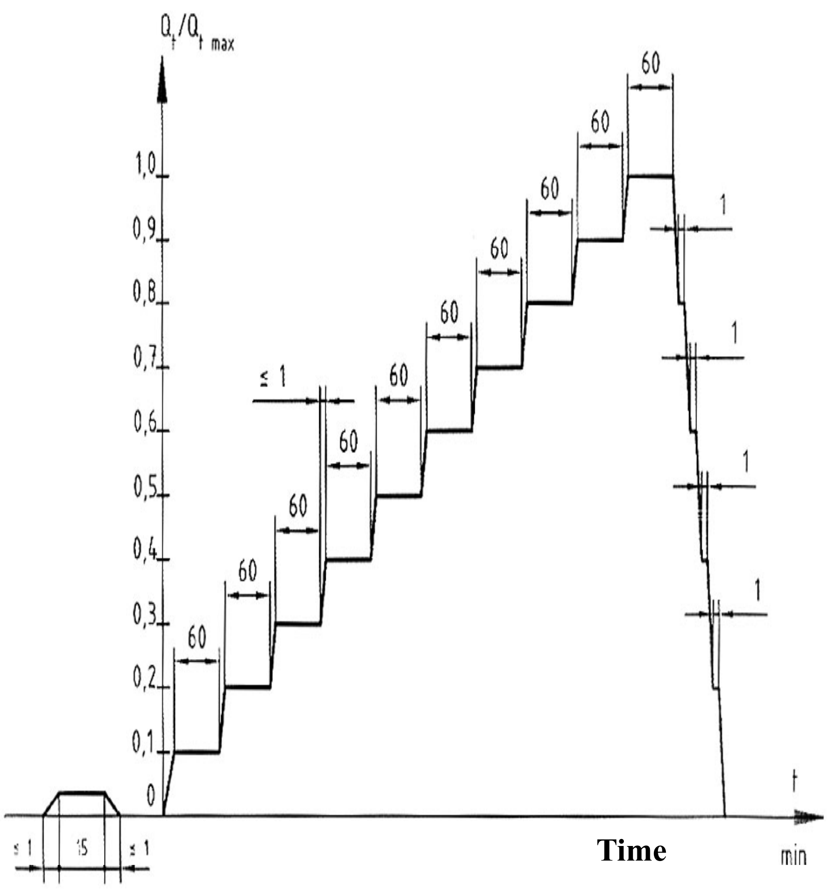
- **Control test:**

  Maximum load test = 1,3 x Q_{ELS} (Fascicule 62)
  = 1,4 x Q_{ELS} (DTU)

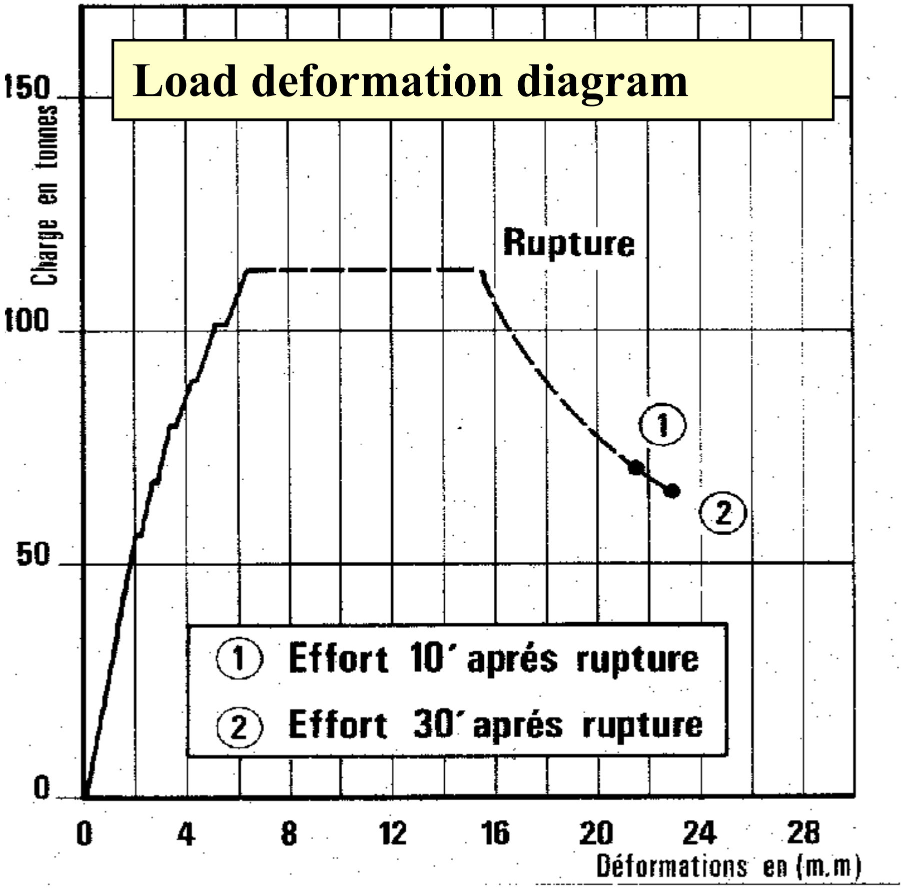
  with Q_{ELS} = serviceability limit state load (for permanent loads)

MICROPILES - LOAD TESTING -

Compression load test program



Test load example



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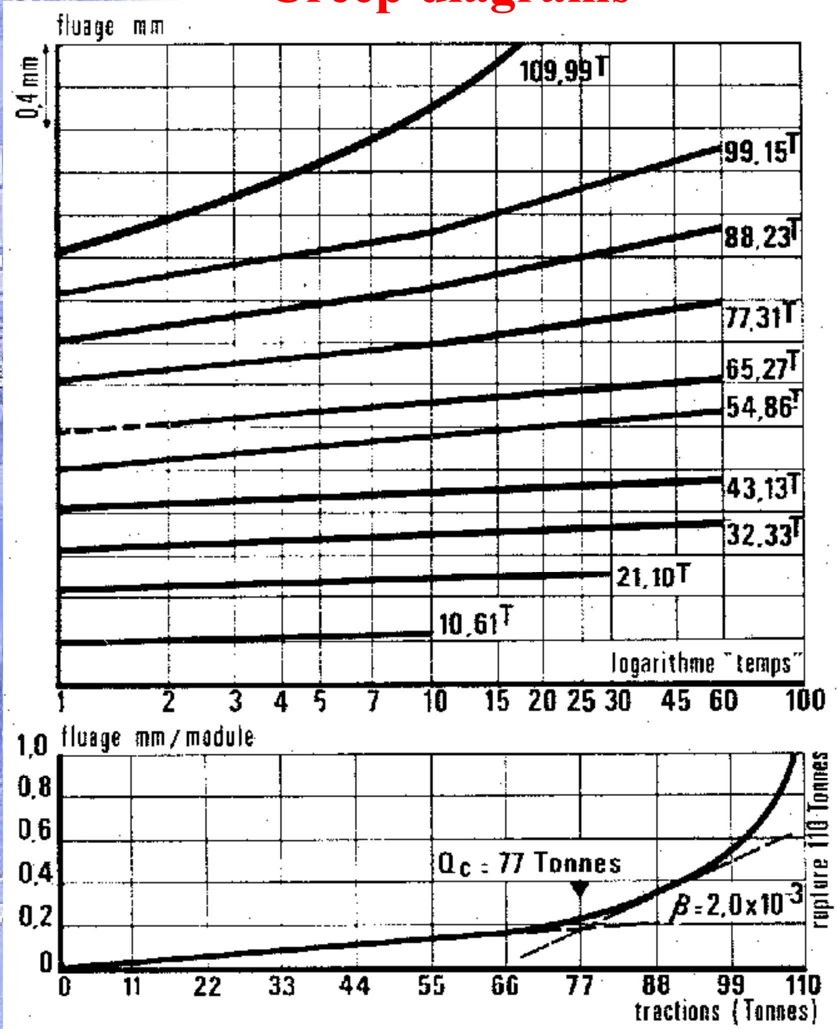
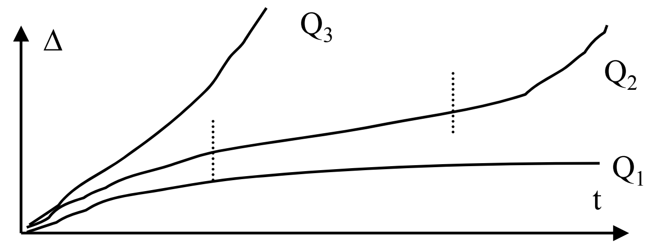
MICROPILES - LOAD TESTING - (compression)

Creep diagrams



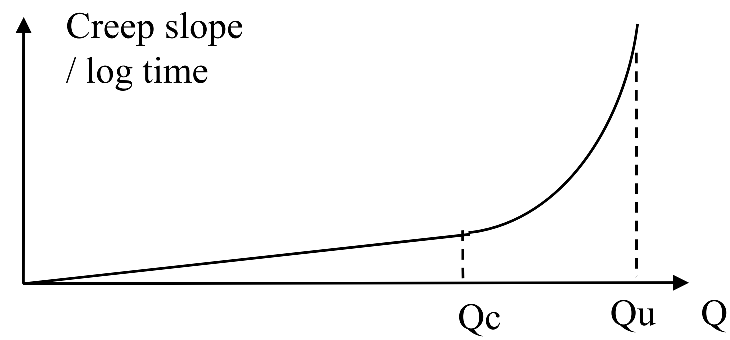


From the test:

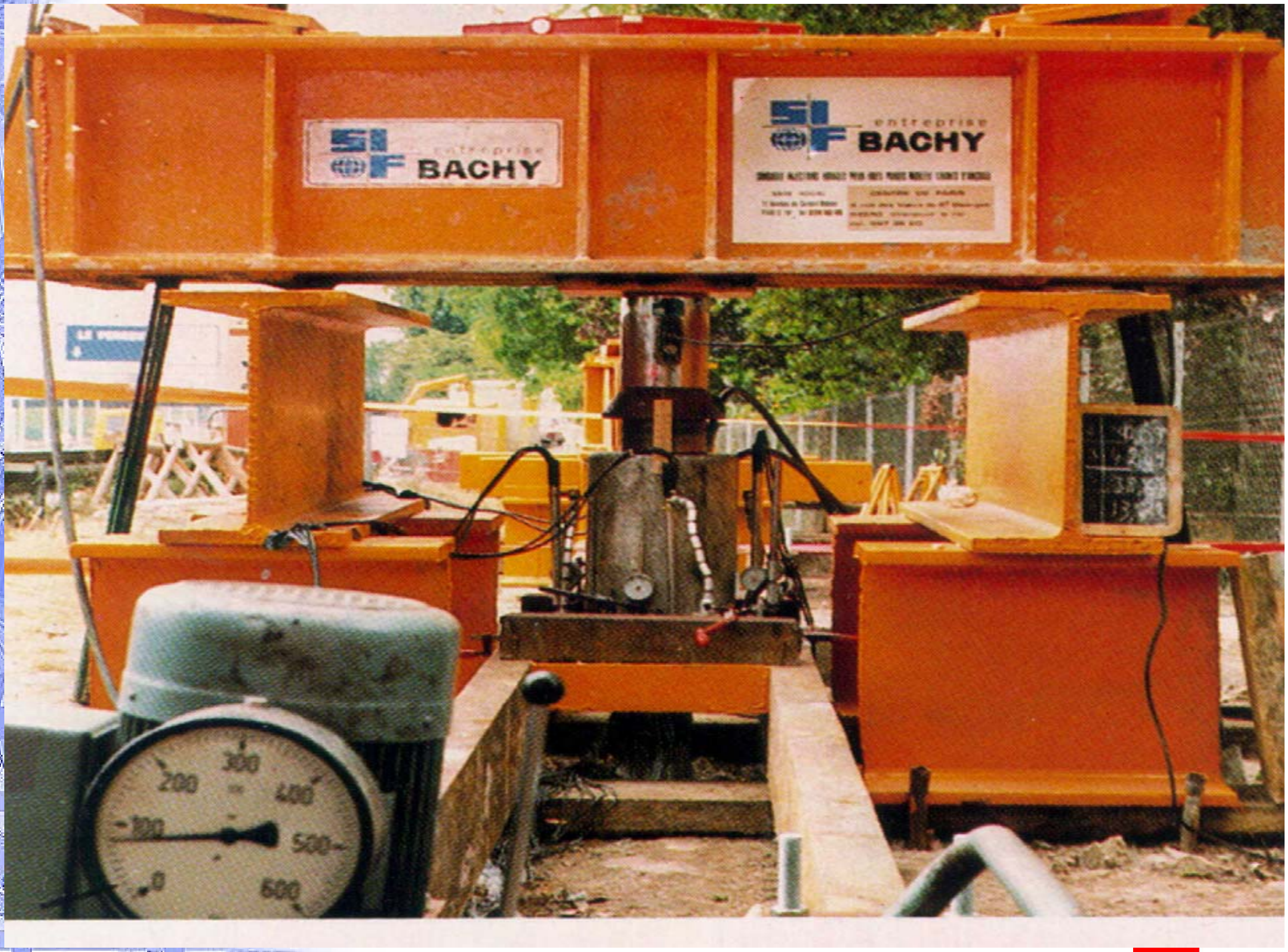
we plot:

- The creep curves for each load
- The diagram of the creep speed in log time at 60 min versus load.

We determine the two characteristic loads Q_C (creep load) and Q_U (ultimate load)



MICROPILES - LOAD TESTING - (compression)



MICROPILE - CONNECTION CONSIDERATIONS -

- **RECOMMENDED CHECKING**
  - Steel characteristics
  - Connections

- **EXAMPLE OF CONNECTION FOR LOAD TRANSFER**
  - For pile bridge foundation
  - For slab

MICROPILE - CONNECTION CONSIDERATIONS -

RECOMMENDED CHECKING

Steel characteristics:

Some samples could be taken for characteristics verification.

The verification of the steel quality is particularly important if re-used tubes are employed.

Connections :

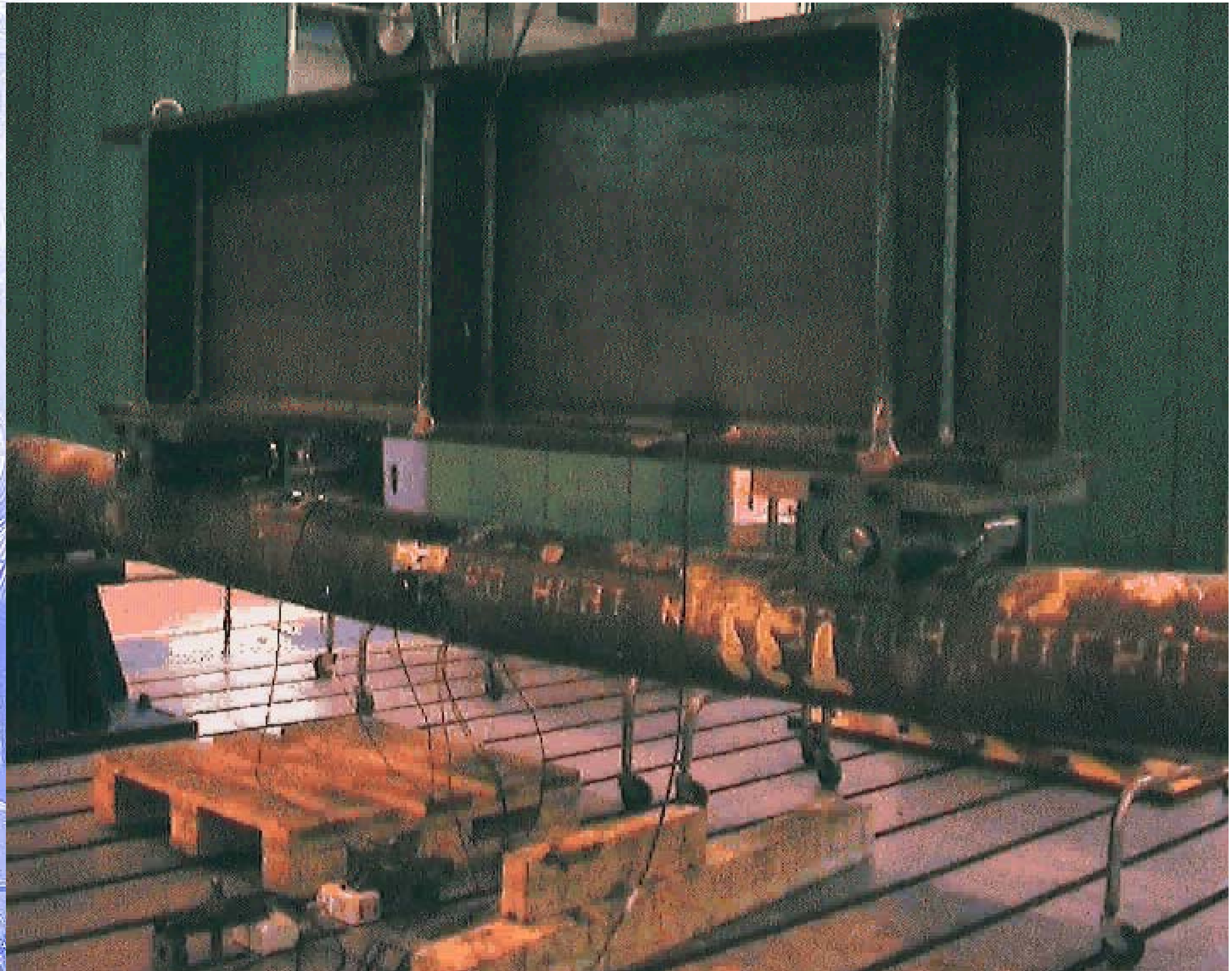
According to their effective working area, the efficiency of the connection shall be proved by calculation or reference to tests already done.

One example of an already completed test is shown on the next slide

MICROPILE - CONNECTION CONSIDERATIONS -

RECOMMENDED CHECKING

Example of connection test



MICROPILE – CONNECTION CONSIDERATIONS -

RECOMMENDED CHECKING

Example of connection test

The result is a failure at the base of the thread at the coupler extremity.

It is absolutely necessary to take into account the reduction of the section area for load capacity.
This must be done for both tension and compression, and for any kind of connection used.

MICROPILE – CONNECTION CONSIDERATIONS -

EXAMPLES OF CONNECTIONS FOR LOAD TRANSFER

- **Pile bridge foundation:**
  - Anchor plate with nut on bars
- **Slab connection**
  - Anchor plate fixed on tube by coupler

MICROPILE - CONNECTION CONSIDERATIONS -

Example of anchor plate on bars for pile bridge foundation

MICROPILE - CONNECTION CONSIDERATIONS -

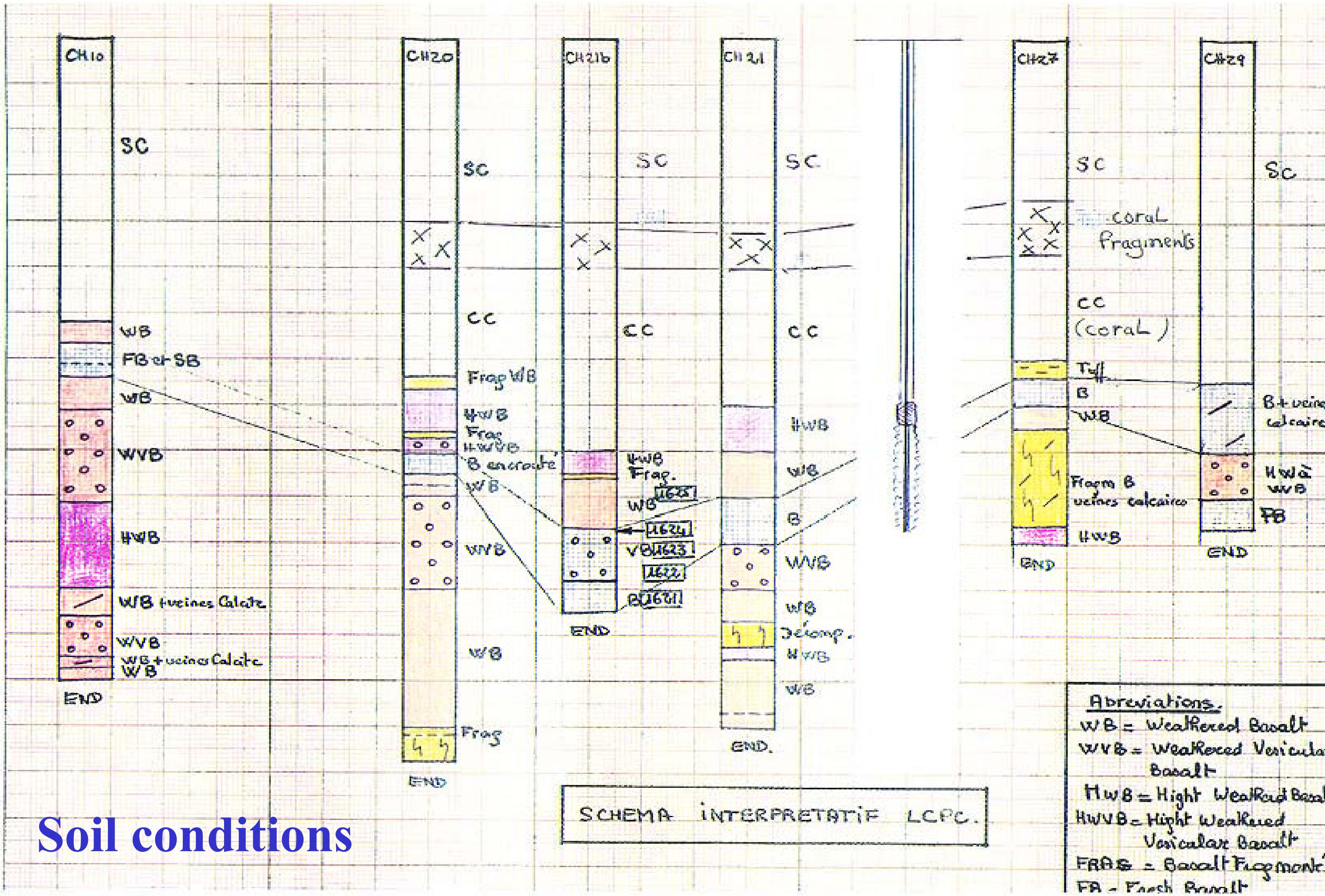
Example of anchor plate fixed on tube for slab reinforcement connection

Paris - cour carrée du Grand Louvre

BORED MICROPILES – MAURITIUS POWER PLANT -

- Soil conditions
- Choice of the solution
- Foundation structure
- Phases of execution
- Micropile head preparation
- Micropile connection with foundation footing

BORED MICROPILES – MAURITIUS POWER PLANT -



Soil conditions

BORED MICROPILES – MAURITIUS POWER PLANT -

Mauritius power plant foundation

Constraints: - Drilling throughout the hard layer of the coral massif

- Anchor must be fixed within the basalt over many meters due to the alternatively strong and weathered layers.

- necessity of reducing the vibration of the mounting block in service

2 possibilities: (piles - micropiles)

•Piles:

- Construction of the rock socket could pose problems in the hard zones.
- Risk of loss of bentonite slury within the coral mass.

•Micropiles:

- Possibility of ensuring the uniformity of the fundation soils by injection of the micropile

Solution: Micropiles were chosen by expert in soil mecanics

BORED MICROPILES – MAURITIUS POWER PLANT -

Mauritius power plant foundation

Micropile difficulties

- Construction tolerance at the micropile head was required to be less thaen 2 cm
- Very limited tolerance in the elevation pile head coupling.

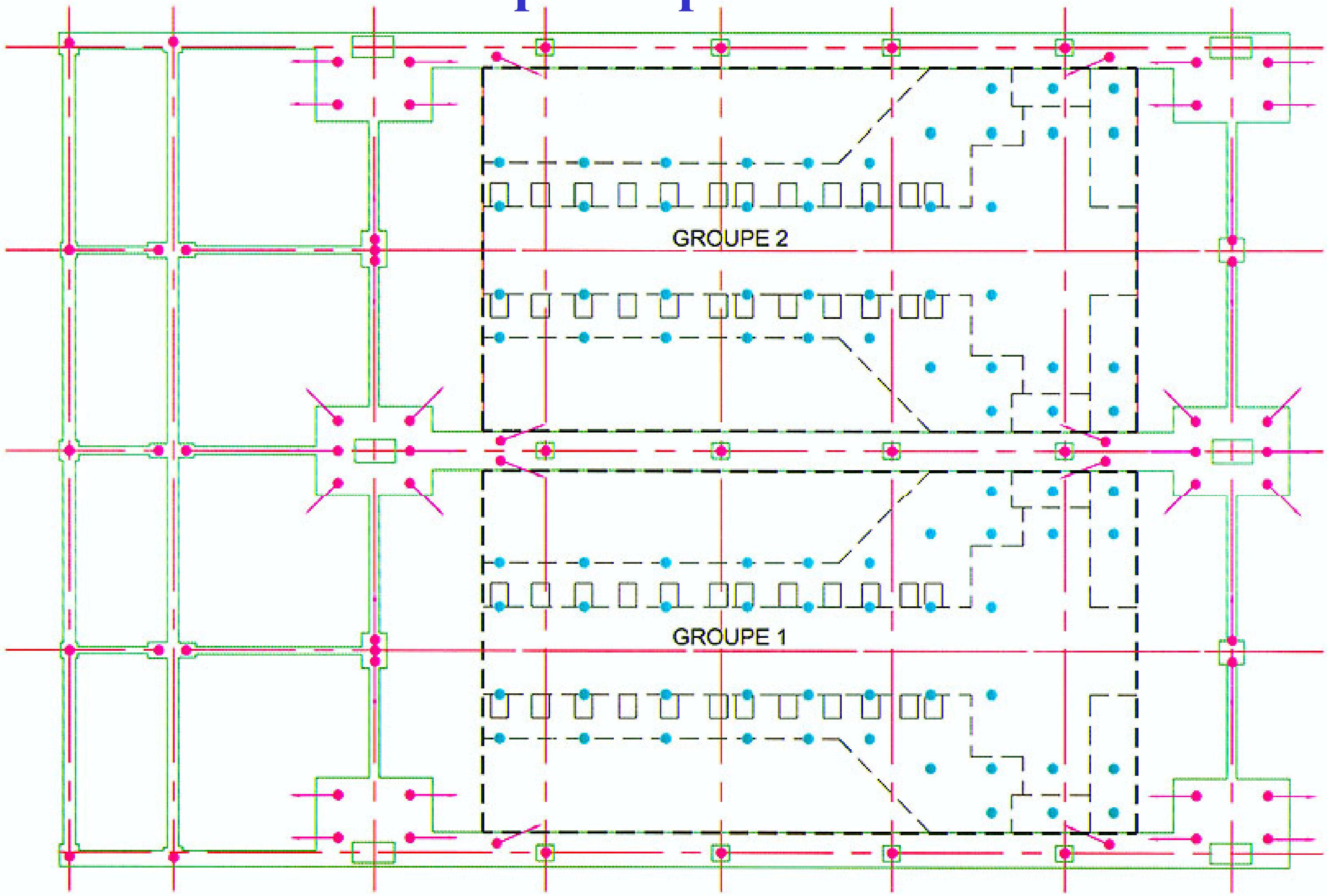
(This was achieved by coring the concrete slab to centralise the micropile, and to allow the level of the pipe to be maintained in the correct position before the set of the grout.

- Grouting with IRS method in weathered basalt.

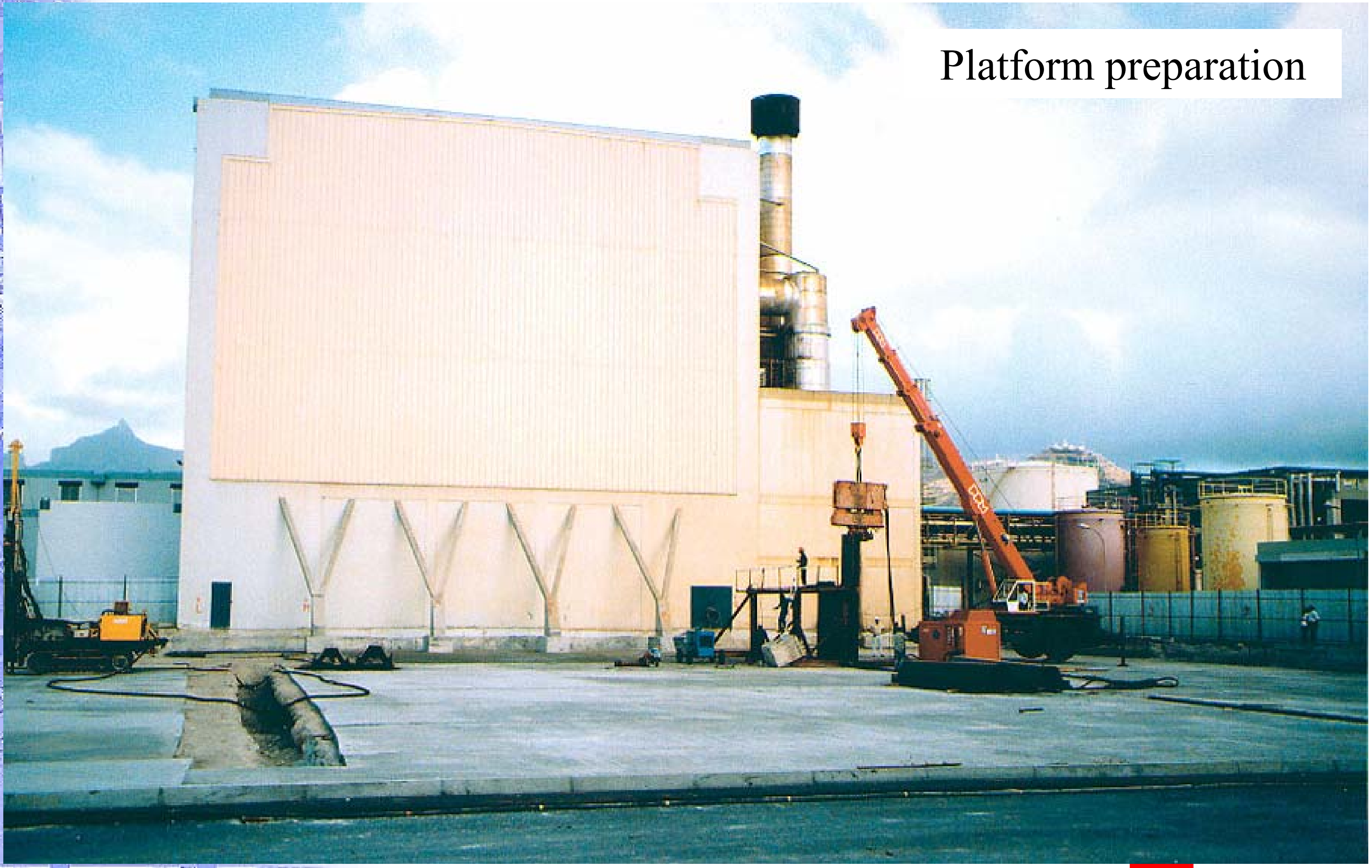
(This was achieved by specific phases of grouting)

BORED MICROPILES – MAURITIUS POWER PLANT -

Mauritius power plant foundation



BORED MICROPILES – MAURITIUS POWER PLANT -



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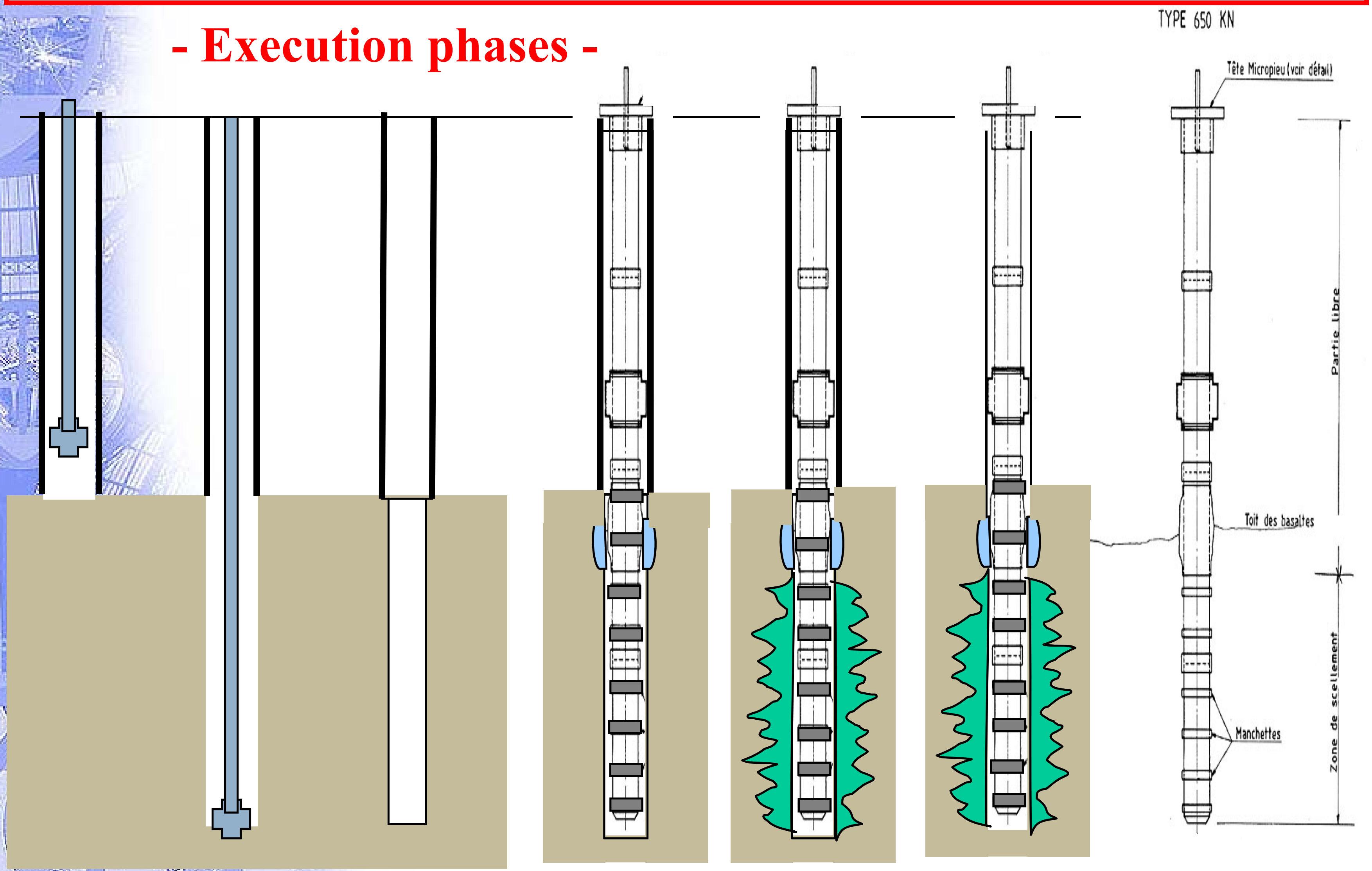
BORED MICROPILES – MAURITIUS POWER PLANT -

POWER PLANT STRUCTURE FOUNDATION

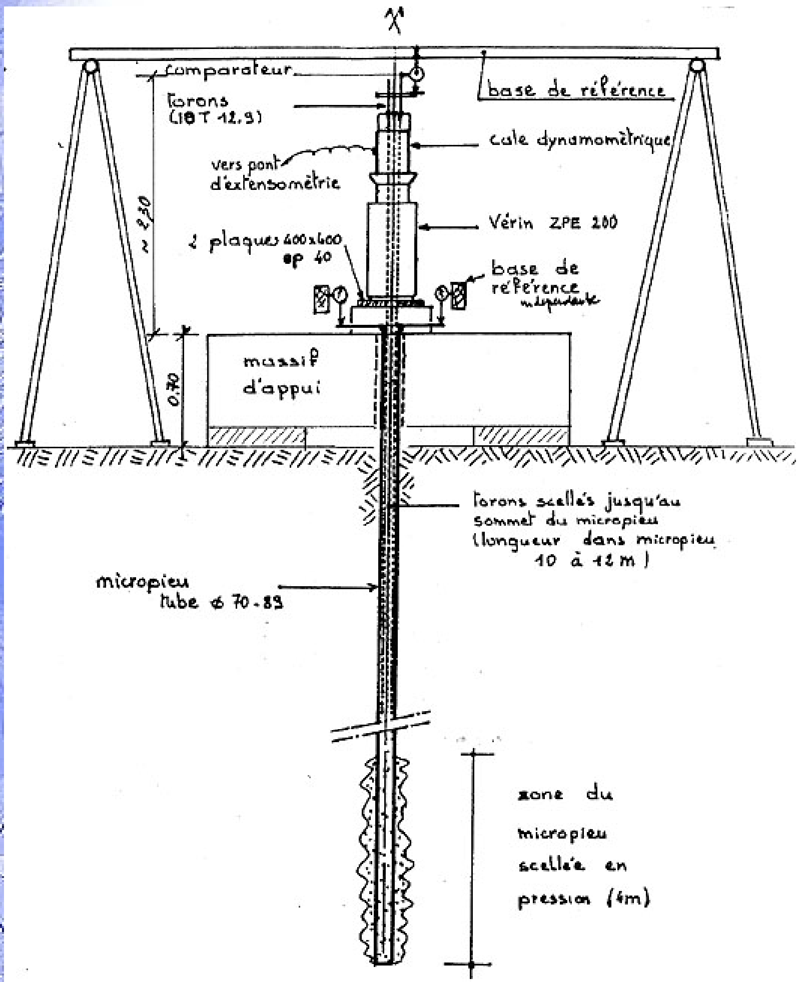
micropile drilling with down hole hammer

BORED MICROPILES – MAURITIUS POWER PLANT -

- Execution phases -

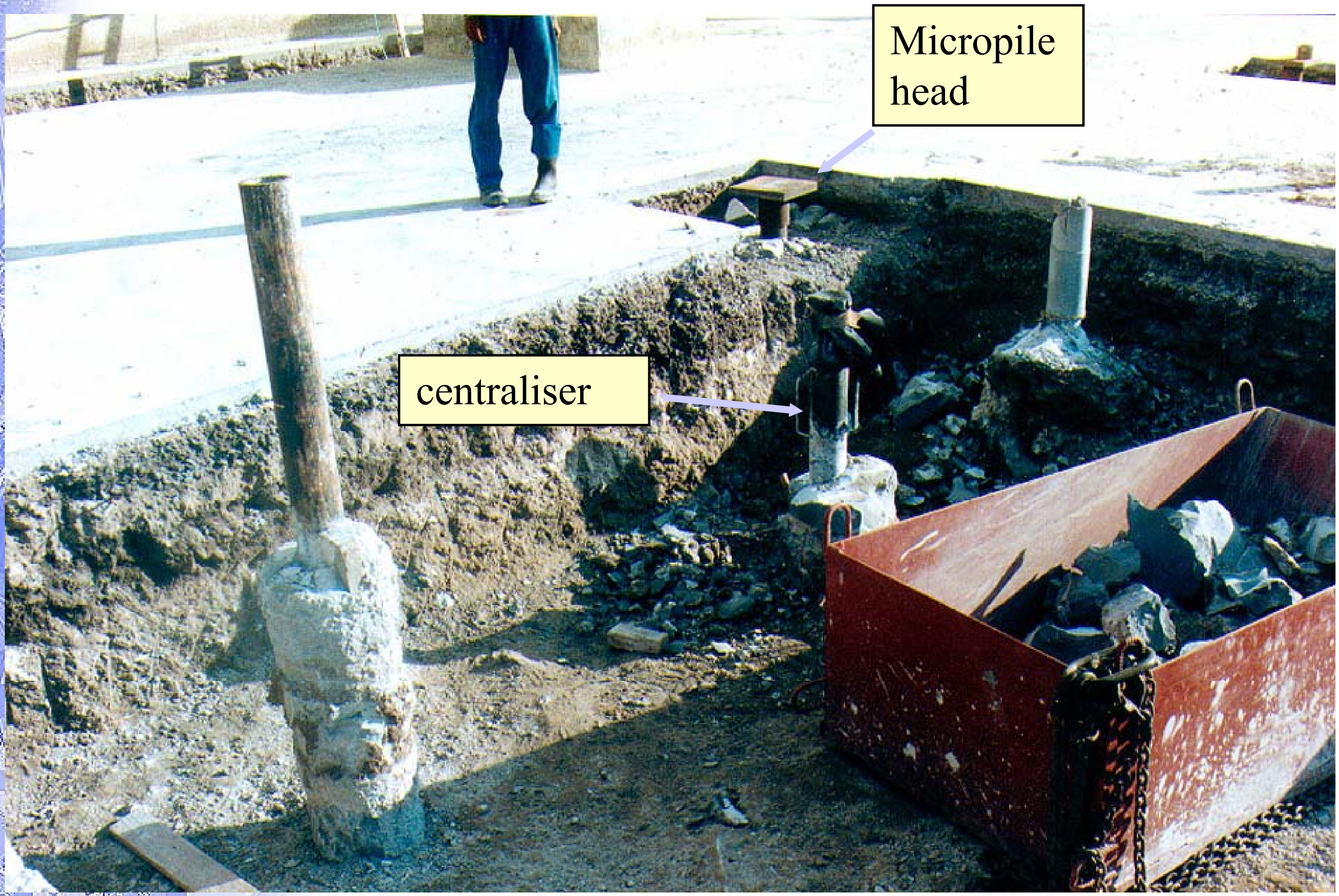


BORED MICROPILES – MAURITIUS POWER PLANT -



BORED MICROPILES – MAURITIUS POWER PLANT -

BORED MICROPILES – MAURITIUS POWER PLANT -



BORED MICROPILES – MAURITIUS POWER PLANT -

Micropile head preparation of the connection for anchor plate

BORED MICROPILES – MAURITIUS POWER PLANT -

Anchor plate example in place at the top of the micropiles

BORED MICOPILES

- END -

THANK YOU FOR YOUR ATTENTION