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
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 \( P \geq 1 \text{ Mpa} \) (type III)
- Bonded using “tube à manchettes” under repetitive and selective grouting (IRS) with \( P \geq 1 \text{ Mpa} \) (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
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)
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 “Injection Globale Unitaire” 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 equipped 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. “Injection Repetitive Selective” with > 1 MPa
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

Rubber sleeve

4 to 6 mm diameter holes
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
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).

Ultimate load

Grouting pressure (bars)

<table>
<thead>
<tr>
<th>Material</th>
<th>Grouting Pressure (bars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flandes clay</td>
<td></td>
</tr>
<tr>
<td>Limestone</td>
<td></td>
</tr>
<tr>
<td>Sand and gravel</td>
<td></td>
</tr>
<tr>
<td>Sables et graviers (alluvions)</td>
<td></td>
</tr>
<tr>
<td>Schiste</td>
<td></td>
</tr>
<tr>
<td>Parnes et caillouses</td>
<td></td>
</tr>
<tr>
<td>Marl</td>
<td></td>
</tr>
<tr>
<td>Flandes clay</td>
<td></td>
</tr>
<tr>
<td>Sand and gravel</td>
<td></td>
</tr>
<tr>
<td>Sables et graviers (alluvions)</td>
<td></td>
</tr>
<tr>
<td>Schiste</td>
<td></td>
</tr>
<tr>
<td>Parnes et caillouses</td>
<td></td>
</tr>
<tr>
<td>Marl</td>
<td></td>
</tr>
<tr>
<td>Flandes clay</td>
<td></td>
</tr>
<tr>
<td>Sand and gravel</td>
<td></td>
</tr>
<tr>
<td>Sables et graviers (alluvions)</td>
<td></td>
</tr>
<tr>
<td>Schiste</td>
<td></td>
</tr>
<tr>
<td>Parnes et caillouses</td>
<td></td>
</tr>
<tr>
<td>Marl</td>
<td></td>
</tr>
</tbody>
</table>
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 $\rightarrow \sigma'_c \leq 8$ 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: \( Q_s = p \int h_i \cdot q_{si} \)

With: \( p = \) micropile equivalent circumference

- \( \text{type I et II}: p = \) drilling circumference
- \( \text{type III}: p = \) drilling circumference \( \times 1,2 \)
- \( \text{type IV}: p = \) drilling circumference \( \times 1,5 \)

\( h_i = \) thickness of the soil layer « i »

\( q_{si} = \) ultimate skin friction \( q_s \) 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)

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

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

\[ P_l = 0.5 \text{ Mpa} \rightarrow q_{si} = 80 \text{ KPa} \]
\[ P_l = 2 \text{ MPa} \rightarrow q_{si} = 120 \text{ KPa} \]

A \( \rightarrow \) Clayey sand, silt or clay
B \( \rightarrow \) Dense to very dense sand or gravel
C \( \rightarrow \) Soft to fragmented chalk
E \( \rightarrow \) Marl or clay stone
F \( \rightarrow \) 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 $k = \frac{Q_{ELU}}{Q_{ELS}}$

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

$$\sigma_{ELU} \leq 0.8 \times \sigma_e \quad \text{(Yield value)}$$

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 $\sigma_{ELS}$

**We calculate the strength $\sigma_{ELS}$:**

$$\sigma_{ELS} = \frac{\sigma_{ELU}}{k} = \frac{(0.8 \times \sigma_e)}{k}$$

for example if $k=1.4$ ----> $\sigma_{ELS} = 0.57 \times \sigma_e \quad \text{(Yield value)}$ (with a maximum of $0.6 \times \sigma_e$)
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

$$Q_C = Q_{TC} = 0.7 \times Q_{SU}$$

With:

$$Q_{SU} = P \int_0^b q_s(z) \, dz$$

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:

<table>
<thead>
<tr>
<th>Load combinations</th>
<th>Limit state</th>
<th>Design load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental</td>
<td>Ultimate (ELU=ULS)</td>
<td>$Q_{ELU} \leq Q_U/1.4$ that means $Q_{su}/1.40$</td>
</tr>
<tr>
<td>Accidental</td>
<td>Ultimate (ELU=ULS)</td>
<td>$Q_{ELU} \leq Q_U/1.2$ that means $Q_{su}/1.20$</td>
</tr>
<tr>
<td>Rare (characteristic)</td>
<td>Serviceability (ELS=SLS)</td>
<td>$Q_{ELS} \leq Q_C/1.1$ that means $Q_{su}/1.57$</td>
</tr>
<tr>
<td>Quasi permanent</td>
<td>Serviceability (ELS=SLS)</td>
<td>$Q_{ELS} \leq Q_C/1.4$ that means $Q_{su}/2.00$</td>
</tr>
</tbody>
</table>
BORED MICROPILES - CAPACITY -

Soils classification for fascicule 62

<table>
<thead>
<tr>
<th>type of soil</th>
<th>category</th>
<th>Pressuremeter $P_1$ (Mpa)</th>
<th>Penetrometer $q_c$ (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay, silt</td>
<td>A</td>
<td>&lt; 0.7</td>
<td>&lt; 3.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.2 - 2.0</td>
<td>3.0 - 6.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>&gt; 2.8</td>
<td>&gt; 6.0</td>
</tr>
<tr>
<td>Sand, gravel</td>
<td>A</td>
<td>&lt; 0.5</td>
<td>&lt; 5.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.0 - 2.0</td>
<td>8.0 - 15.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>&gt; 2.5</td>
<td>&gt; 20.0</td>
</tr>
<tr>
<td>Chalk</td>
<td>A</td>
<td>&lt; 0.7</td>
<td>&lt; 5.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.0 - 2.6</td>
<td>&gt; 6.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>&gt; 3.0</td>
<td>-</td>
</tr>
<tr>
<td>Marl and claystone</td>
<td>A</td>
<td>Soft</td>
<td>1.5 - 4.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>&gt; 4.5</td>
<td>-</td>
</tr>
<tr>
<td>Rock</td>
<td>A</td>
<td>Weathered</td>
<td>2.5 - 4.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Fractured</td>
<td>&gt; 4.5</td>
</tr>
</tbody>
</table>

Choice of the curve for $q_s$ determination

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

Choice of the curve for $q_s$ determination

GEOTECHNICAL CAPACITY

Fascicule 62

qs determination

I.S.M 2009 London (10th to 13th may) 9th International workshop on micropiles by A. Jaubertou
BORED MICROPILES - CAPACITY -

GEOTECHNICAL CAPACITY (with FASCICULE 62)

Curves for skin friction ($q_s$) value determination upon pressuremeter values

---

I.S.M 2009 London (10th to 13th may) 9th International workshop on micropiles - by A. Jaubertou -
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: $Q_i = Q_{\text{measured}} / 1.2$ 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:

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Limit state</th>
<th>Design load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental</td>
<td>Ultimate (ELU=ULS)</td>
<td>$Q_{ELU} \leq Q_U/1.4$</td>
</tr>
<tr>
<td>Accidental</td>
<td>Ultimate (ELU=ULS)</td>
<td>$Q_{ELU} \leq Q_U/1.2$</td>
</tr>
<tr>
<td>Rare</td>
<td>Serviceability (ELS=SLS)</td>
<td>$Q_{ELS} \leq Q_C/1.1$</td>
</tr>
<tr>
<td>Quasi permanent</td>
<td>Serviceability (ELS=SLS)</td>
<td>$Q_{ELS} \leq Q_C/1.4$</td>
</tr>
</tbody>
</table>
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 micropiles (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 \( (Q_1 \text{ ou } Q_{tl}) \) estimated from geotechnical test
  Proof load test = \( Q_{tmax} = 1,5 Q_{tl} \) (for tension load test)
  \( 1,3 Q_1 \) (for compression load test)

- **Control test:**
  Maximum load test = \( 1,3 \times Q_{ELS} \) (Fascicule 62 )
  = \( 1,4 \times Q_{ELS} \) (DTU )
  with \( Q_{ELS} \) = serviceability limit state load (for permanent loads)
MICROPILES - LOAD TESTING -

Compression load test program

Test load example

Load deformation diagram

1. Effort 10' après rupture
2. Effort 30' après rupture
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)
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
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.
EXAMPLES OF CONNECTIONS FOR LOAD TRANSFER

- **Pile bridge foundation:**
  - Anchor plate with nut on bars

- **Slab connection**
  - Anchor plate fixed on tube by coupler
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
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 slurry 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 mechanics
Mauritius power plant foundation

Micropile difficulties

• Construction tolerance at the micropile head was required to be less than 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

GROUPE 1

GROUPE 2
Platform preparation
POWER PLANT
STRUCTURE
FOUNDATION

micropile
drilling with
down hole
hammer
BORED MICROPILES – MAURITIUS POWER PLANT -

- Execution phases -
BORED MICROPILES – MAURITIUS POWER PLANT -

Diagram showing a cross-section and details of a bored micropile installation. The text includes technical specifications and annotations in French.
Breaking out of the pile head
Micropile head preparation of the connection for anchor plate

Coupler
BORED MICROPILES – MAURITIUS POWER PLANT -

Anchor plate example in place at the top of the micropiles
BORED MICOPILES

- END -

THANK YOU FOR YOUR ATTENTION