DEVELOPPEMENT D’UN ELEMENT POUTRE INCORPORE :

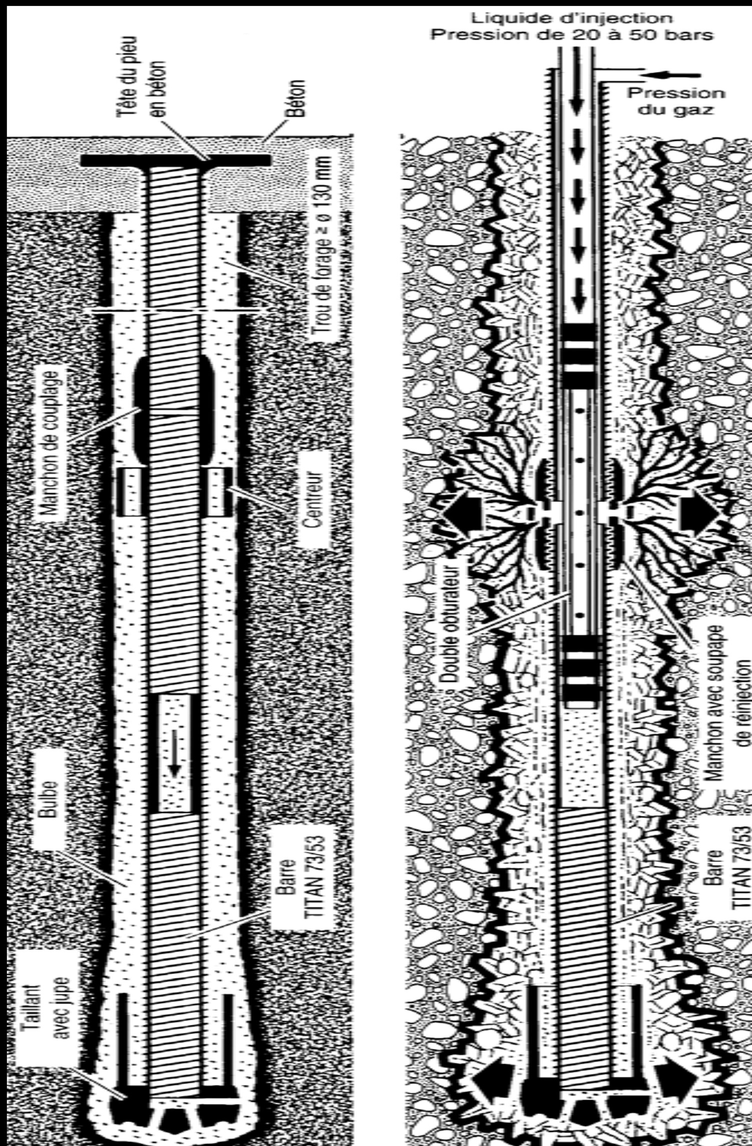
APPLICATION A L’ETUDE DES GROUPES ET DES RESEAUX DE MICROPIEUX

Hussein Mroueh, LML, UMR8107
Université des Sciences et Technologies de Lille

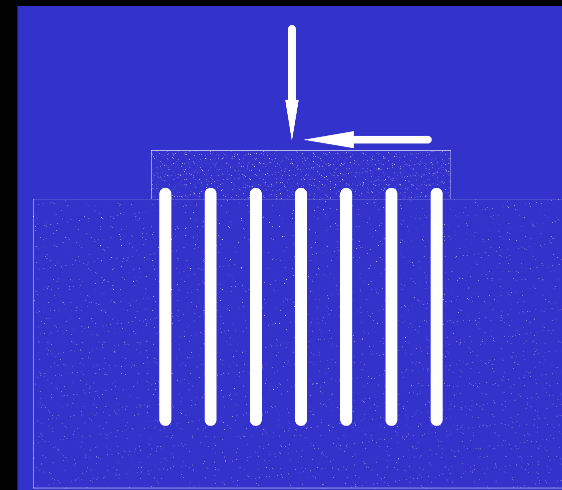
LABORATOIRE de MECANIQUE de LILLE
UMR CNRS 8107
E.C. LILLE
E.N.S.A.M.
U.S.T.L.

USTL

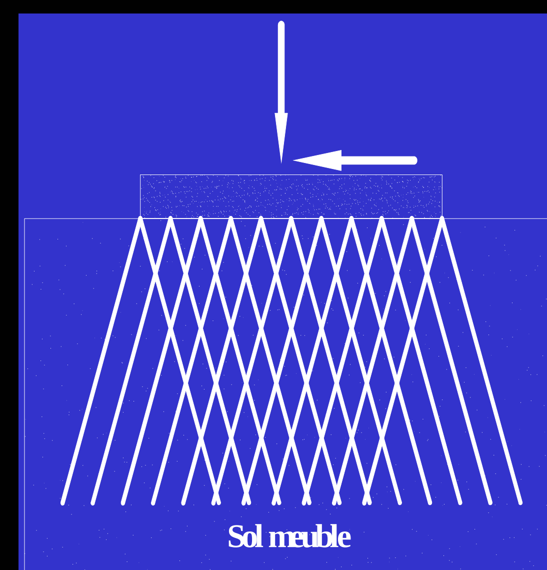
Micropieux



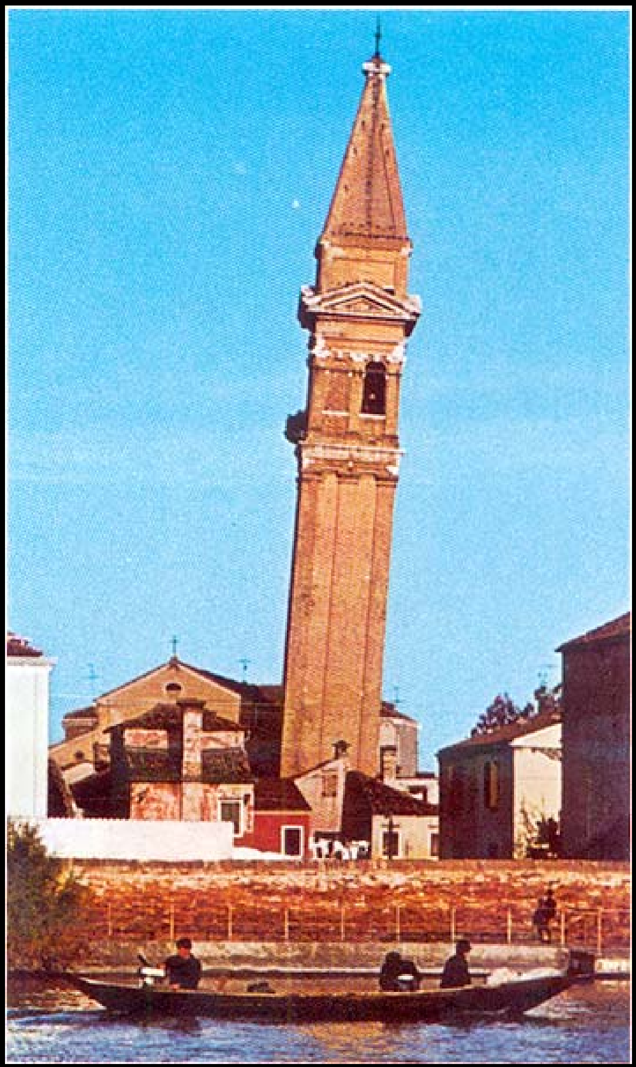
Groupe

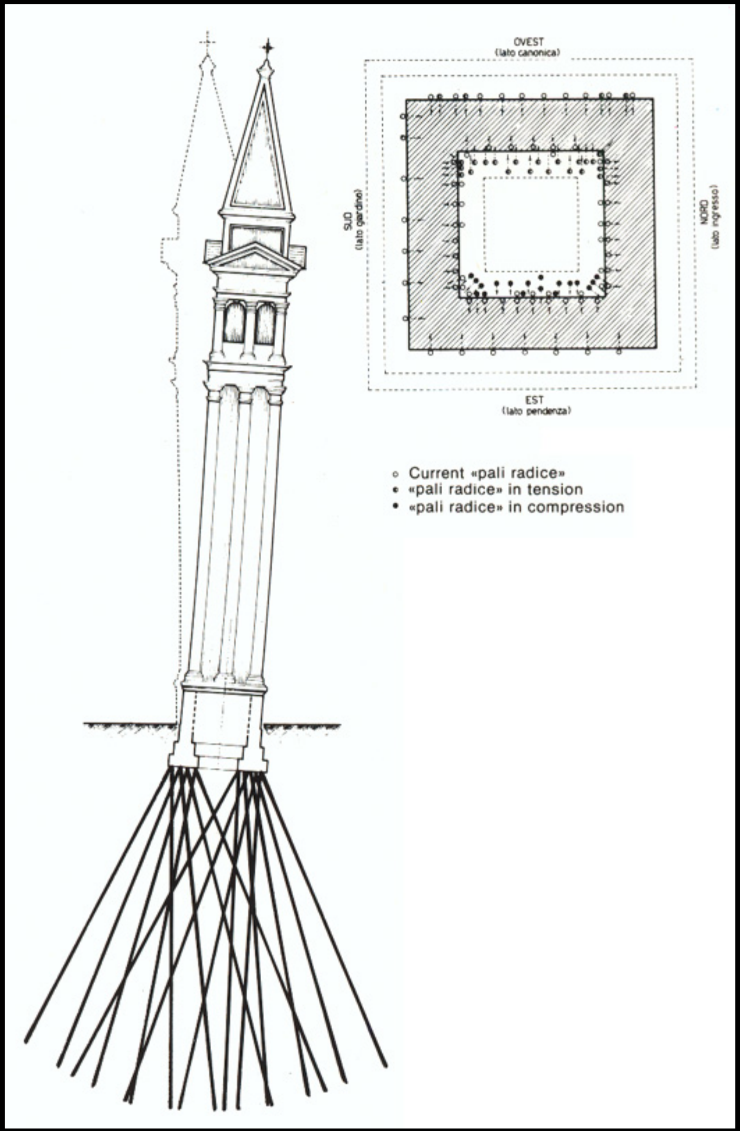


Réseau

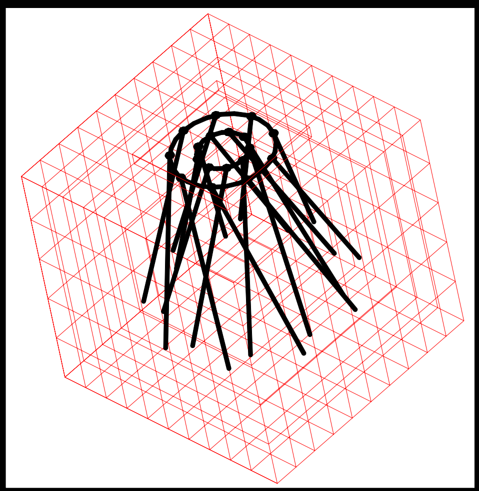


Renforcement de la Tour Burano à Venise (Lizzi 1982)

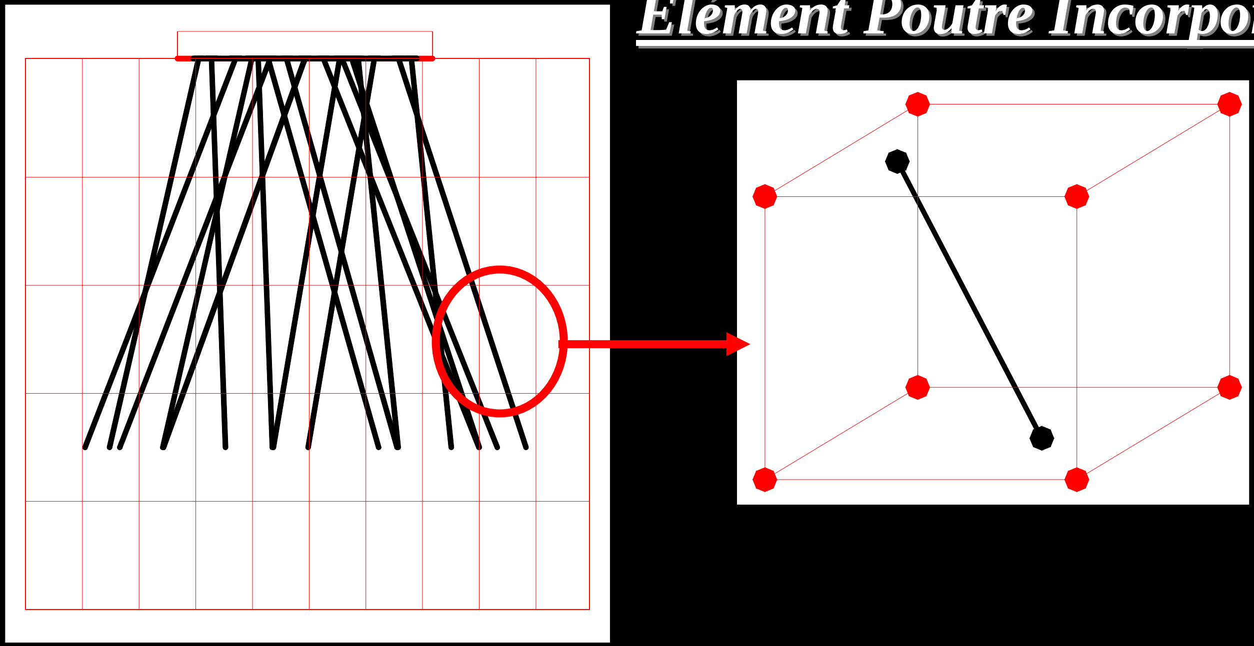




Modélisation numérique : difficultés



Elément Poutre Incorporé



Plan de l'exposé

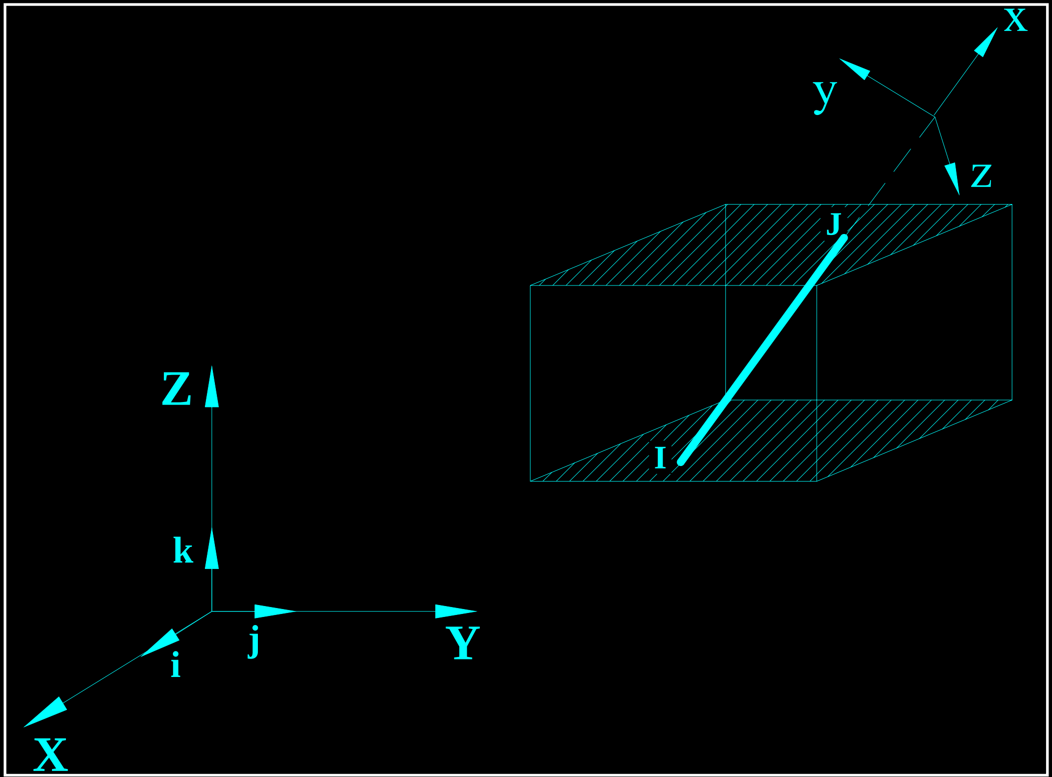
- **Développement et validation:**
  - **a - Formulation avec contact parfait**
  - **b - Formulation avec élément d'interface**

- **Application à un réseau des micropieux**

1ère Partie

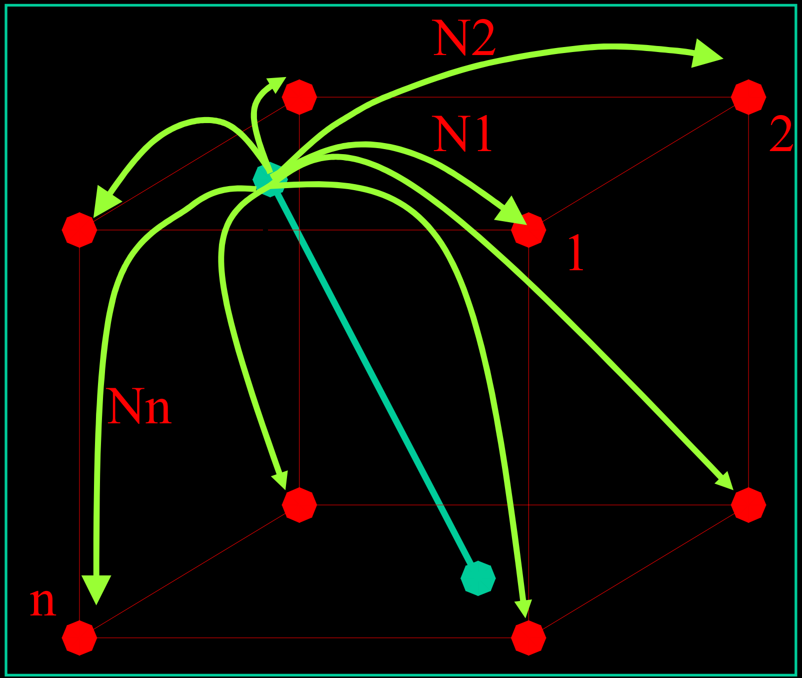
DEVELOPPEMENT ET VALIDATION

FORMULATION AVEC CONTACT PARFAIT



$$R_g^b = \begin{pmatrix} {}^t P^g . R_{l(II)} . P^g & {}^t P^g . R_{l(IJ)} . P^g \\ {}^t P^g . R_{l(JI)} . P^g & {}^t P^g . R_{l(JJ)} . P^g \end{pmatrix}_{(12\times 12)}$$

INTERPOLATION DES DEPLACEMENTS



$$\begin{pmatrix} U^b_{xI} \\ U^b_{yI} \\ U^b_{zI} \\ U^b_{xJ} \\ U^b_{yJ} \\ U^b_{zJ} \end{pmatrix} = \begin{pmatrix} N^s_1(X_I).[I] & \rightarrow & N^s_n(X_I).[I] \\ N^s_1(X_J).[I] & \rightarrow & N^s_n(X_J).[I] \end{pmatrix}_{(6\times n)} . \begin{pmatrix} U^s_{x1} \\ U^s_{y1} \\ U^s_{z1} \\ \downarrow \\ U^s_{xn} \\ U^s_{yn} \\ U^s_{zn} \end{pmatrix}$$

FORMULATION

$$\begin{pmatrix} U_I^b \\ \Theta_I^b \\ U_J^b \\ \Theta_J^b \end{pmatrix} = N^{bs} \cdot \begin{pmatrix} U^s \\ \Theta_I^b \\ \Theta_J^b \end{pmatrix} \qquad N^{bs} = \begin{pmatrix} N^s(X_I) & 0 & 0 \\ 0 & I & 0 \\ N^s(X_J) & 0 & 0 \\ 0 & 0 & I \end{pmatrix}$$

$$\boxed{E_b = \frac{1}{2}\, {}^tU^b \cdot R_g^b \cdot U^b}$$

$$E_b = \frac{1}{2} \begin{pmatrix} U^s & \Theta_I & \Theta_J \end{pmatrix} \cdot {}^tN^{bs} \cdot R_g^b \cdot N^{bs} \cdot \begin{pmatrix} U^s \\ \Theta_I \\ \Theta_J \end{pmatrix}$$

$$\boxed{R_g^{bs} = {}^tN^{bs} \cdot R_g^b \cdot N^{bs}}$$

INTRODUCTION DANS PECPLAS

Base de données des ER
(GEOM., PROP MECA)

Discretisation des ER en EPI:
(calcul des intersections avec les EM)

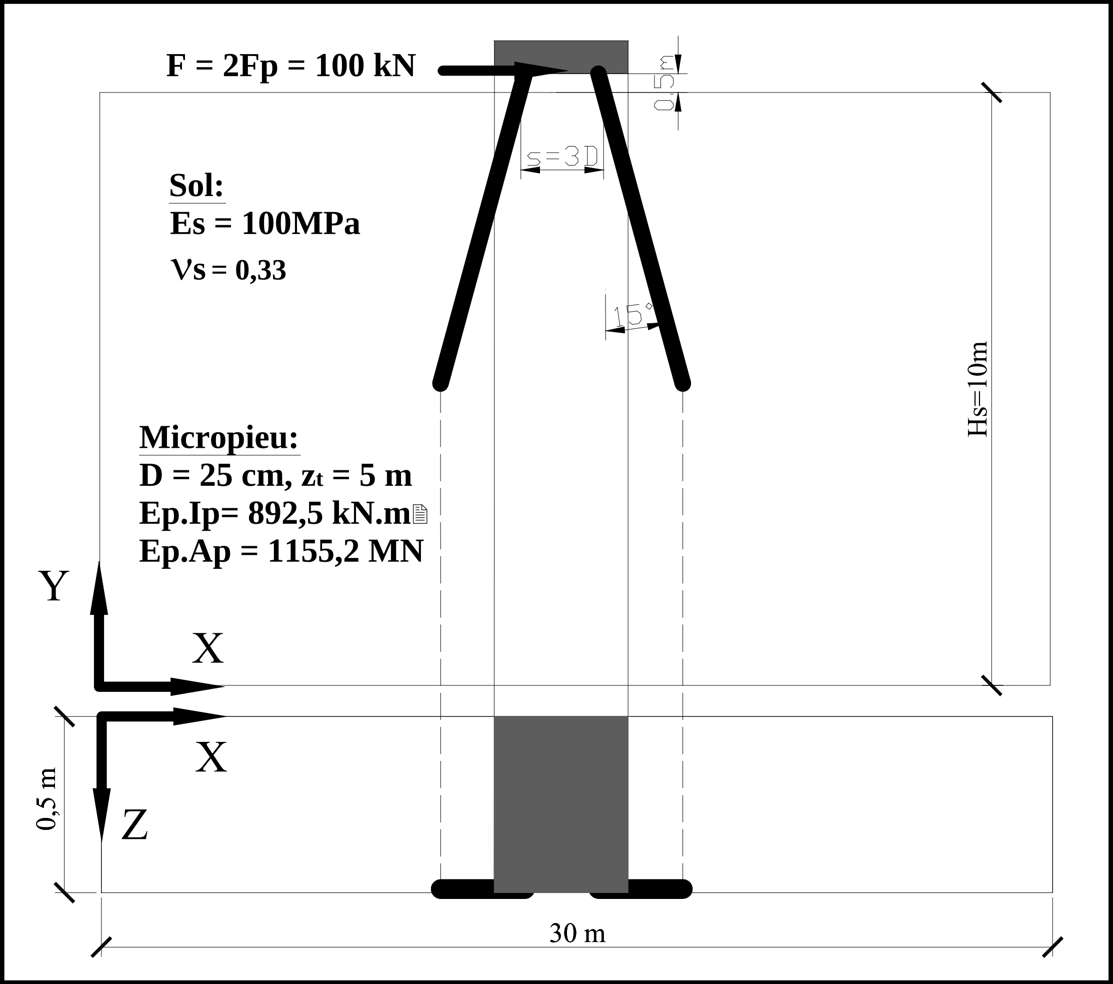
Redimensionner MRG

Calcul de MRE de EPI

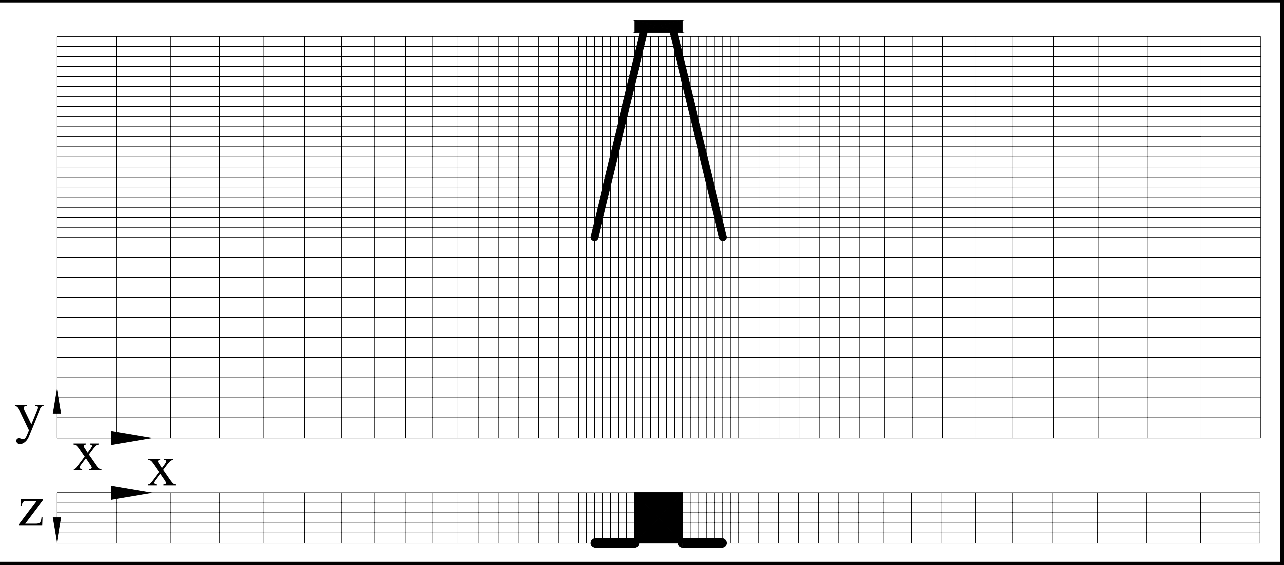
VALIDATION

Confrontation des calculs menés avec l 'EPI avec ceux menés avec l 'EPC

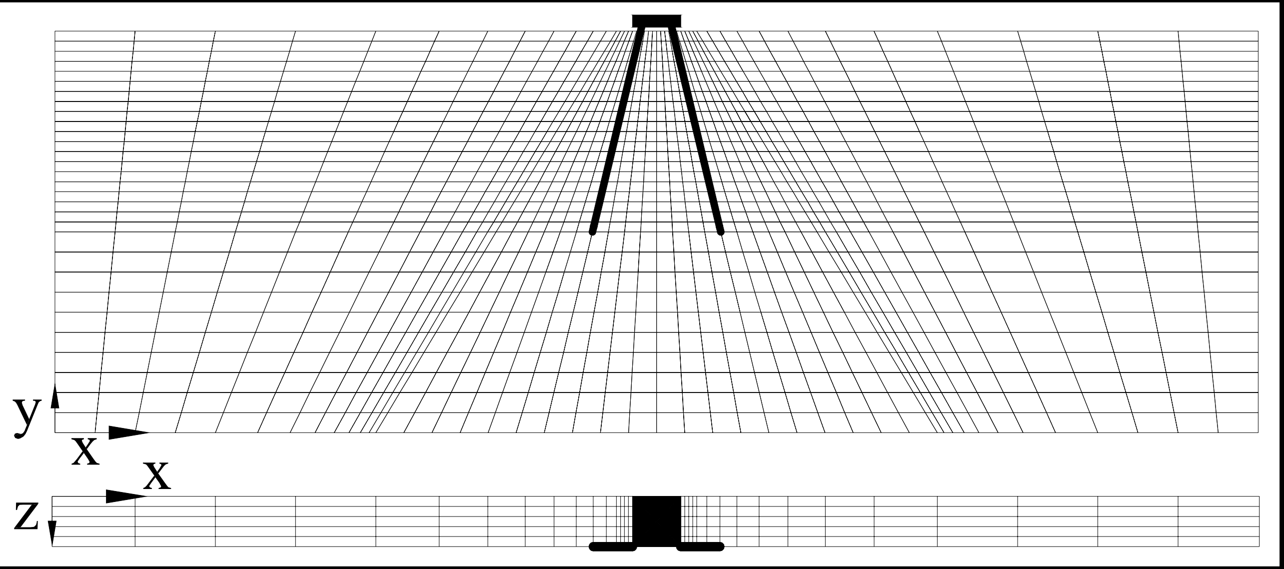
Groupe de deux Micropieux

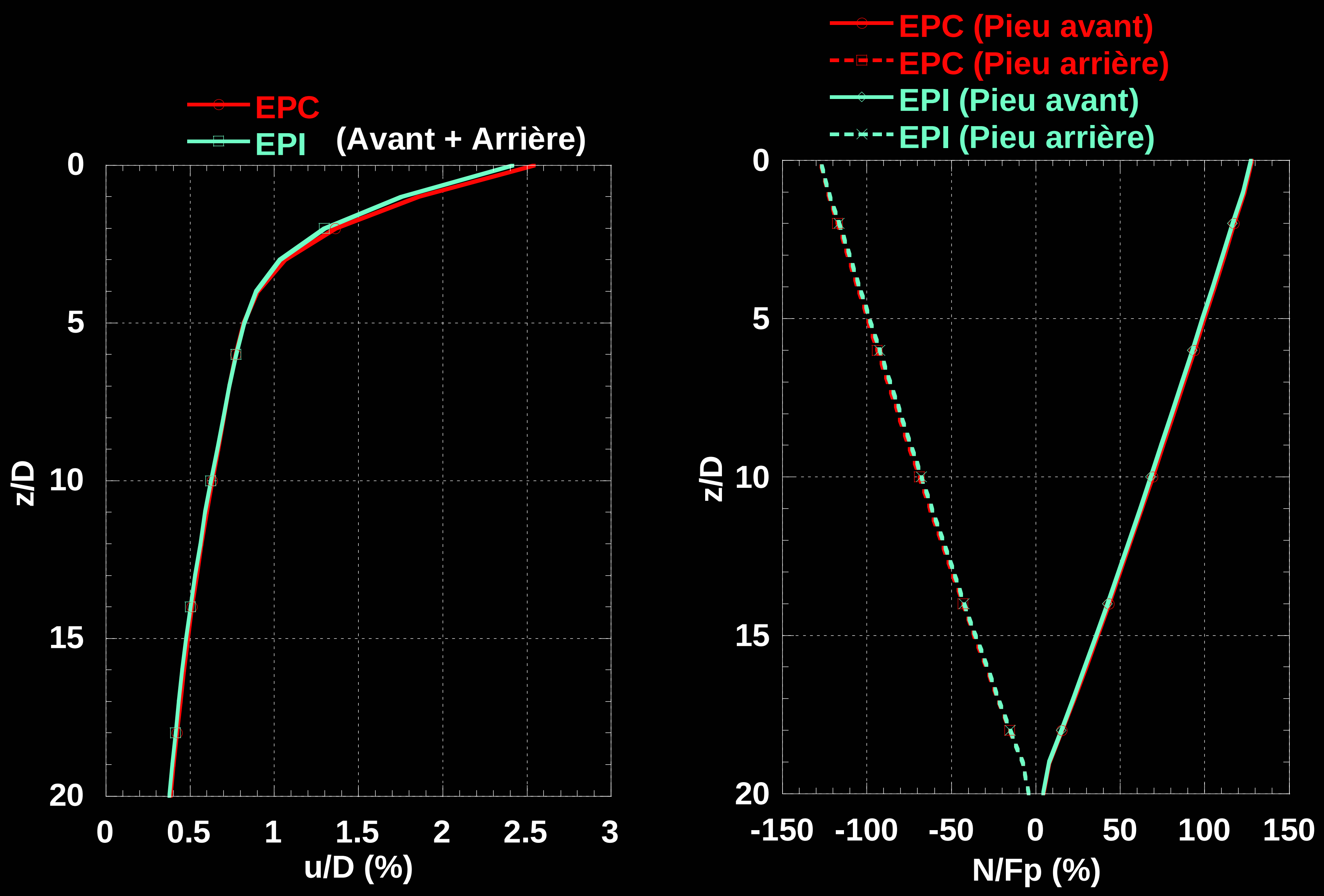


Maillage avec EPI

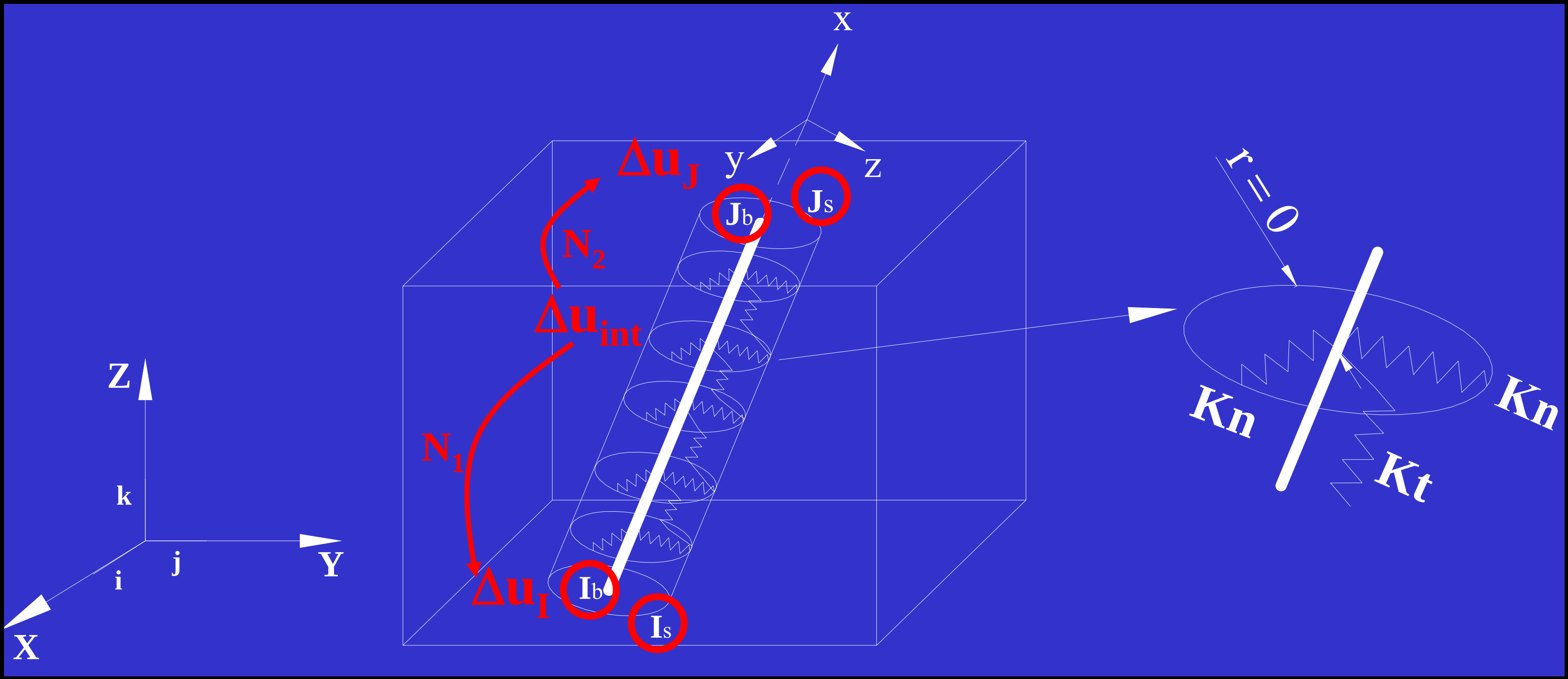


Maillage conventionnel



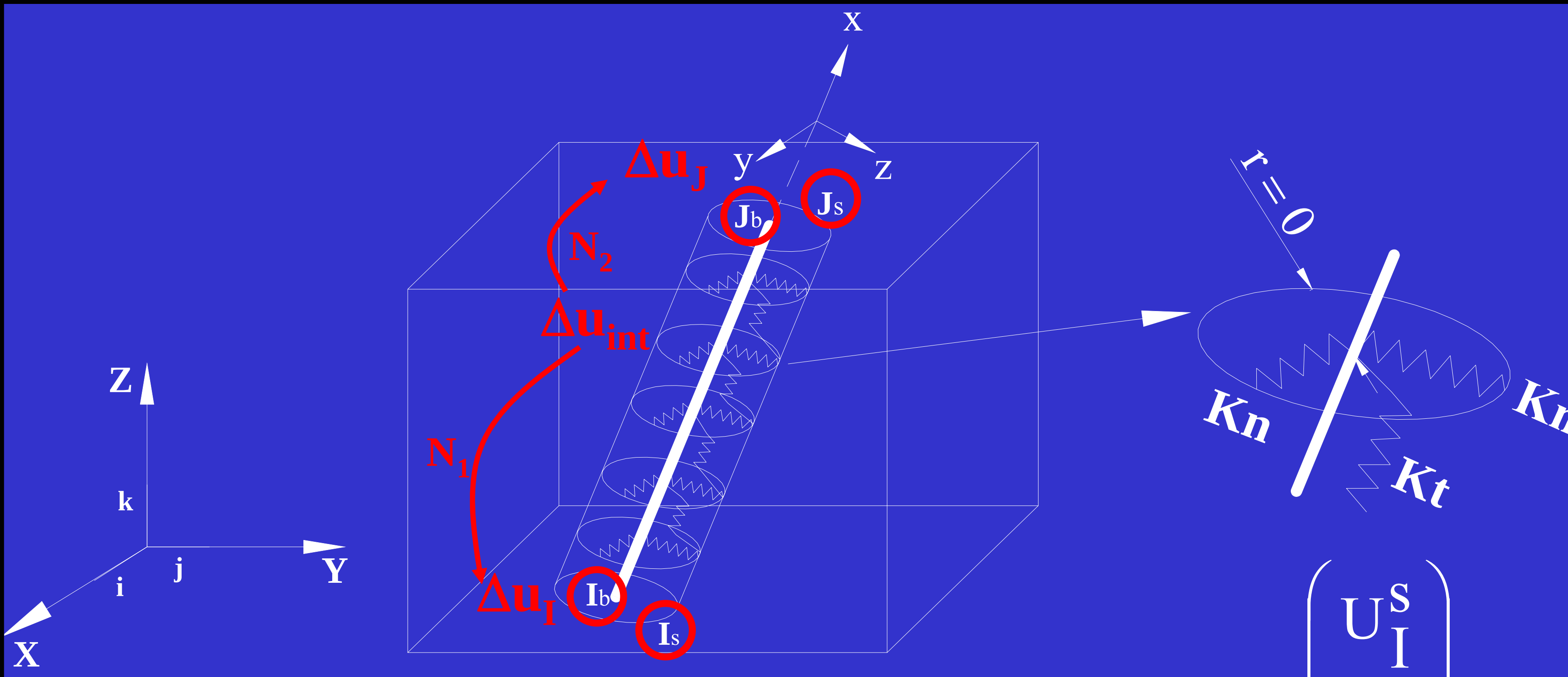

EPC
EPI
(Avant + Arrière)
z/D
u/D (%)
0
0.5
1
1.5
2
2.5
3
5
10
15
20
EPC (Pieu avant)
EPC (Pieu arrière)
EPI (Pieu avant)
EPI (Pieu arrière)
N/Fp (%)
-150
-100
-50
50
100
150

EPI AVEC ELEMENTS D'INTERFACE



$$\boxed{\Delta u^{int} = \begin{pmatrix} N_1.[I] & N_2.[I] \end{pmatrix} . \begin{pmatrix} \Delta u_I \\ \Delta u_J \end{pmatrix}}$$

EPI AVEC ELEMENTS D'INTERFACE



$$\Delta u^{int} = P.\left(N_1[I]\ \ N_2[I]\ \ -N_1[I]\ \ -N_2[I] \right)_{(3\times 12)} \cdot \begin{pmatrix} U_I^S \\ U_J^s \\ U_I^b \\ U_J^b \end{pmatrix}$$

$$\Delta u^{int} = B^{int} . U^{int} = B^{int} . \begin{pmatrix} N^{s}(X_I)_{(3\times 3n)} & [0]_{(3\times 6)} \\ N^{s}(X_J)_{(3\times 3n)} & [0]_{(3\times 6)} \\ [0]_{(6\times 3n)} & [I]_{(6\times 6)} \end{pmatrix}_{[12\times(3n+6)]} . \begin{pmatrix} U^{s} \\ U_I^{b} \\ U_J^{b} \end{pmatrix}$$

$$B^{int} = P . \left(N_1[I] \;\; N_2[I] \;\; -N_1[I] \;\; -N_2[I] \right)$$

$$\boxed{\Delta u^{int} = B^{int} . U^{int} = B^{int} . N^{s}_{int} . U^{int}_{g}}$$

MODÈLE DE COMPORTEMENT MOHR -COULOMB NON ASSOCIÉ

Matrice élastique $\Longrightarrow$ $$C^{in} = \begin{pmatrix} K_t & 0 & 0 \\ 0 & K_n & 0 \\ 0 & 0 & K_n \end{pmatrix}$$

Fonction de charge F_i $\Longrightarrow$ $$F_i(\sigma_n, \tau) = |\tau| - \sigma_n \mathrm{tg}\varphi_i - c_i$$

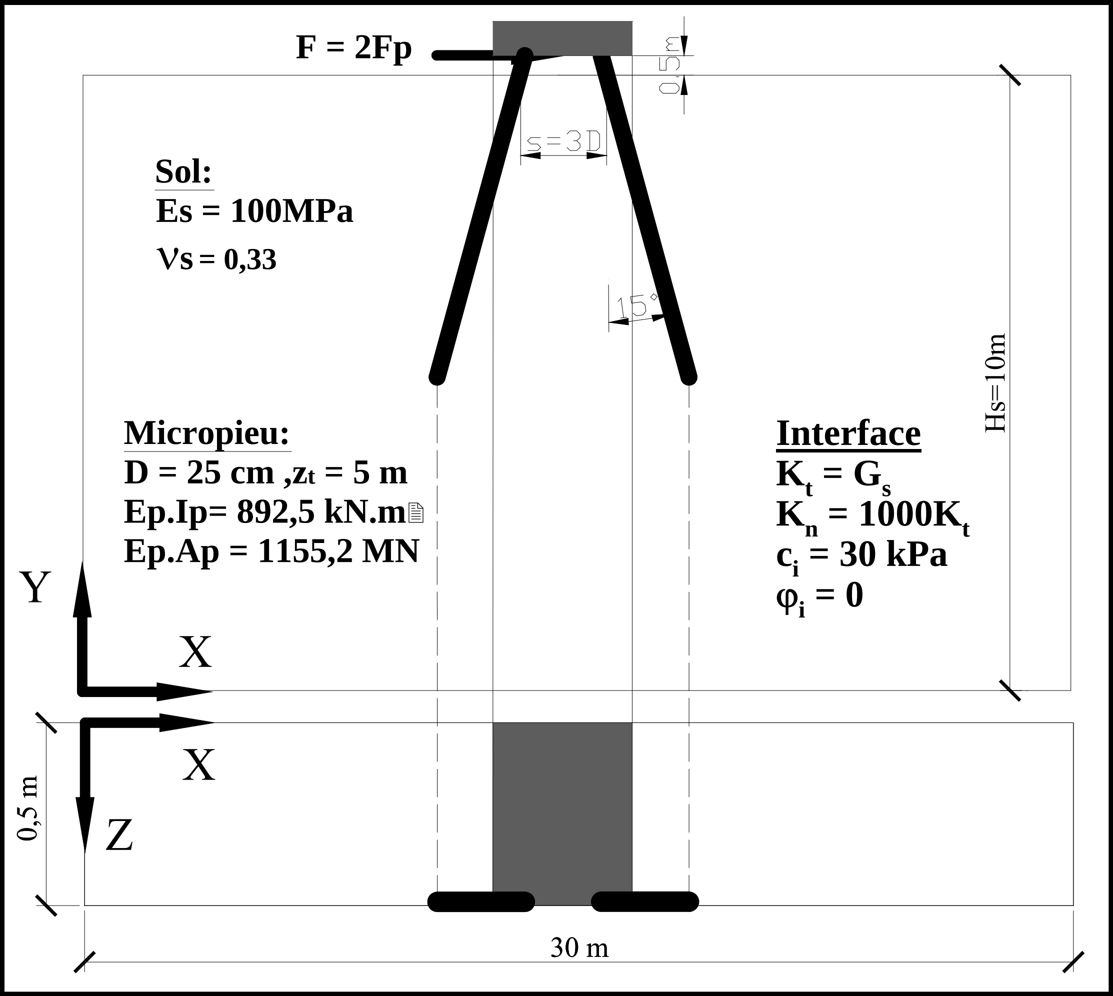
Potentiel plastique G_i $\Longrightarrow$ $$G_i(\sigma_n, \tau) = |\tau| - \sigma_n \mathrm{tg}\psi_i$$

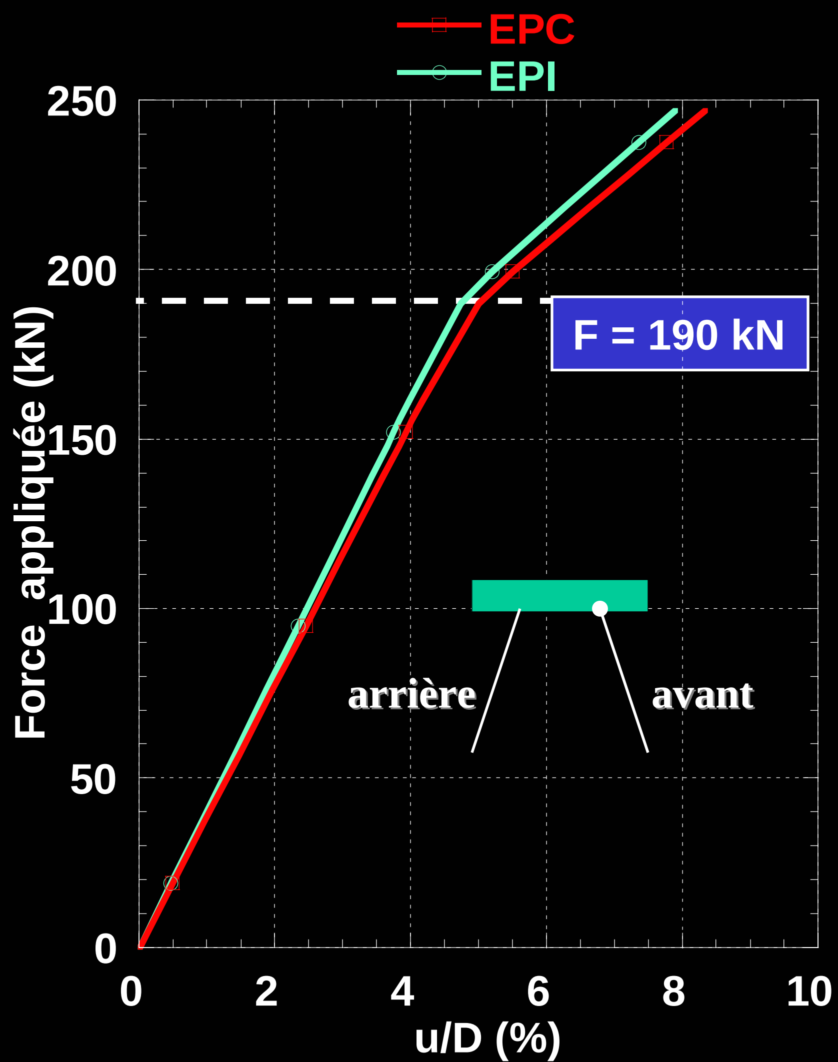
MATRICE DE RIGIDITE ELEMENTAIRE DE L'ELEMENT D'INTERFACE

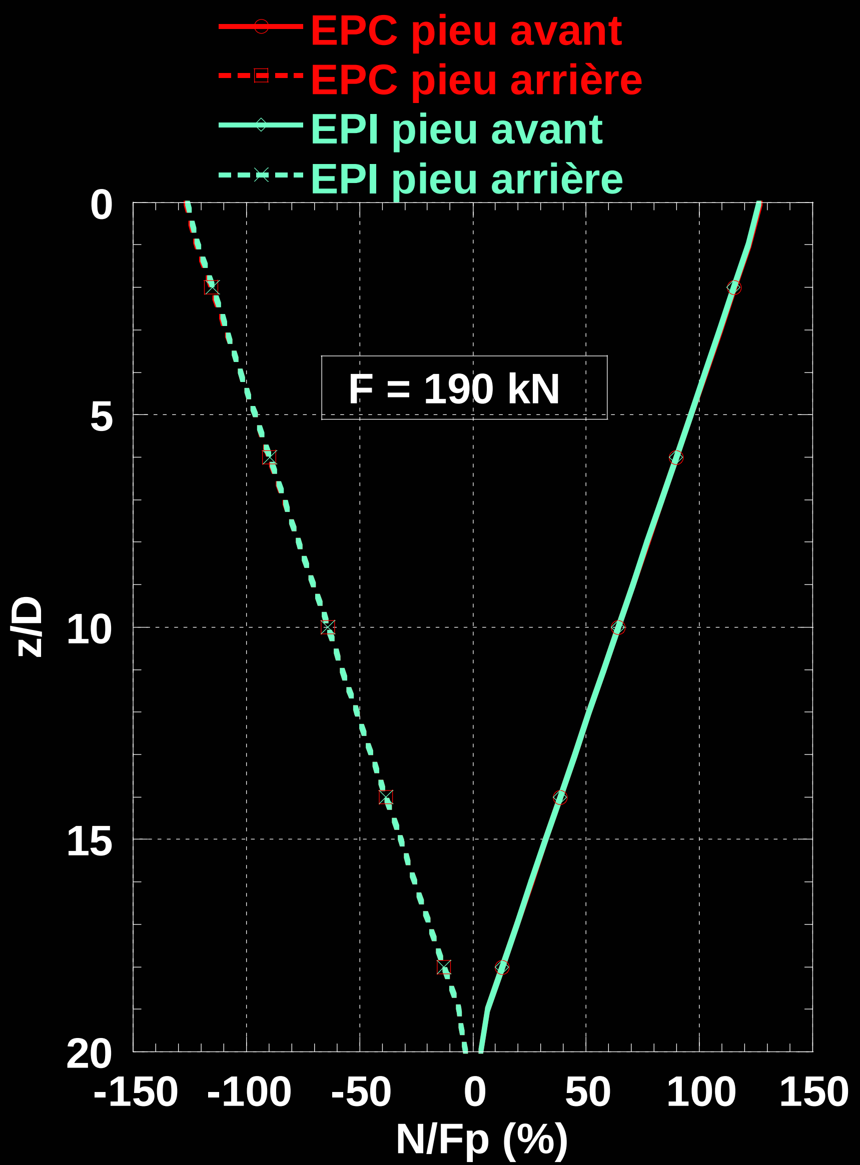
$$\boxed{R_{int} = \int_0^L {}^t N_{int}^s \, . \, {}^t B^{int} . C^{int} . B^{int} . N_{int}^s . d\Gamma}$$

VALIDATION

Groupe de deux Micropieux




EPC
EPI
Force appliquée (kN)
u/D (%)
F = 190 kN
arrière
avant
0
50
100
150
200
250
0
2
4
6
8
10

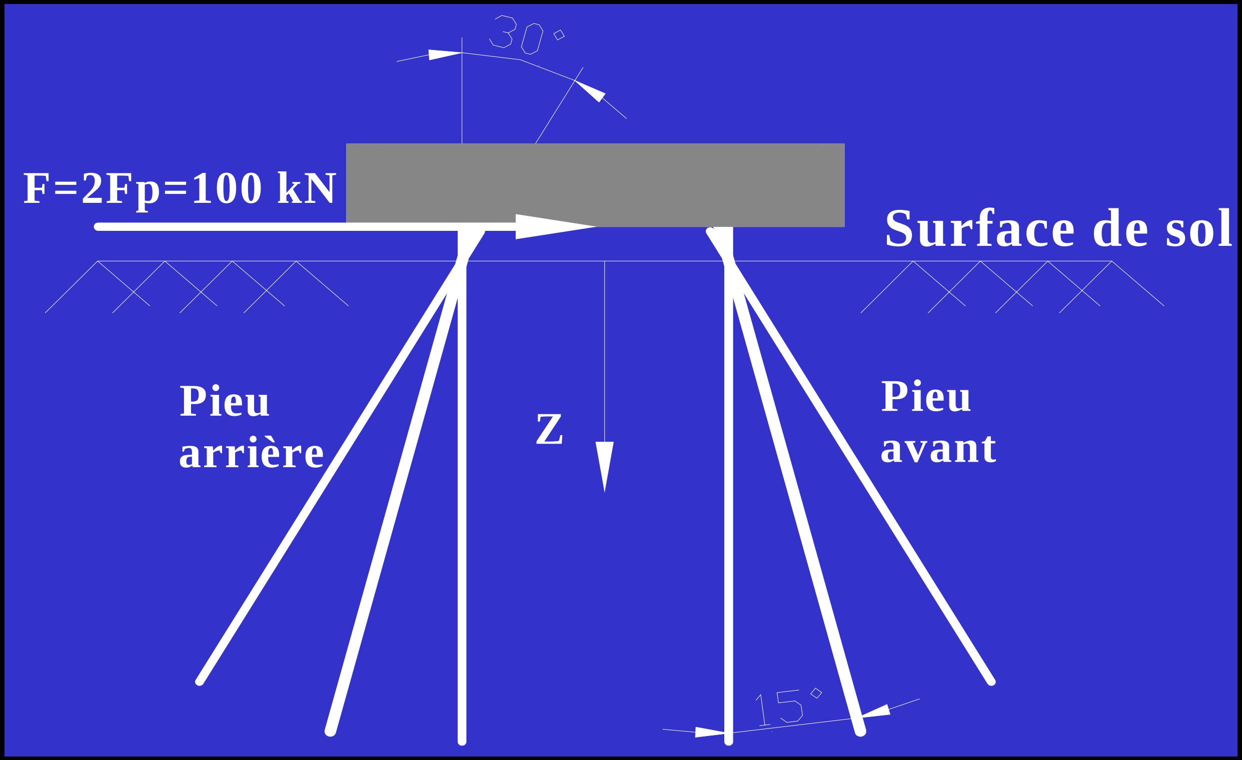

EPC pieu avant
EPC pieu arrière
EPI pieu avant
EPI pieu arrière
F = 190 kN
z/D
N/Fp (%)
0
5
10
15
20
-150
-100
-50
0
50
100
150

2ème Partie

APPLICATION

- **Influence de l’inclinaison sur un groupe de deux micropieux**
- **Etude des essais du CEBTP**
- **Etude d’un réseau en mur**
- **Etude du réseau de Lizzi**

INFLUENCE D'INCLINAISON
CONTACT PARFAIT



Micropieux

L=5m, S = 3D

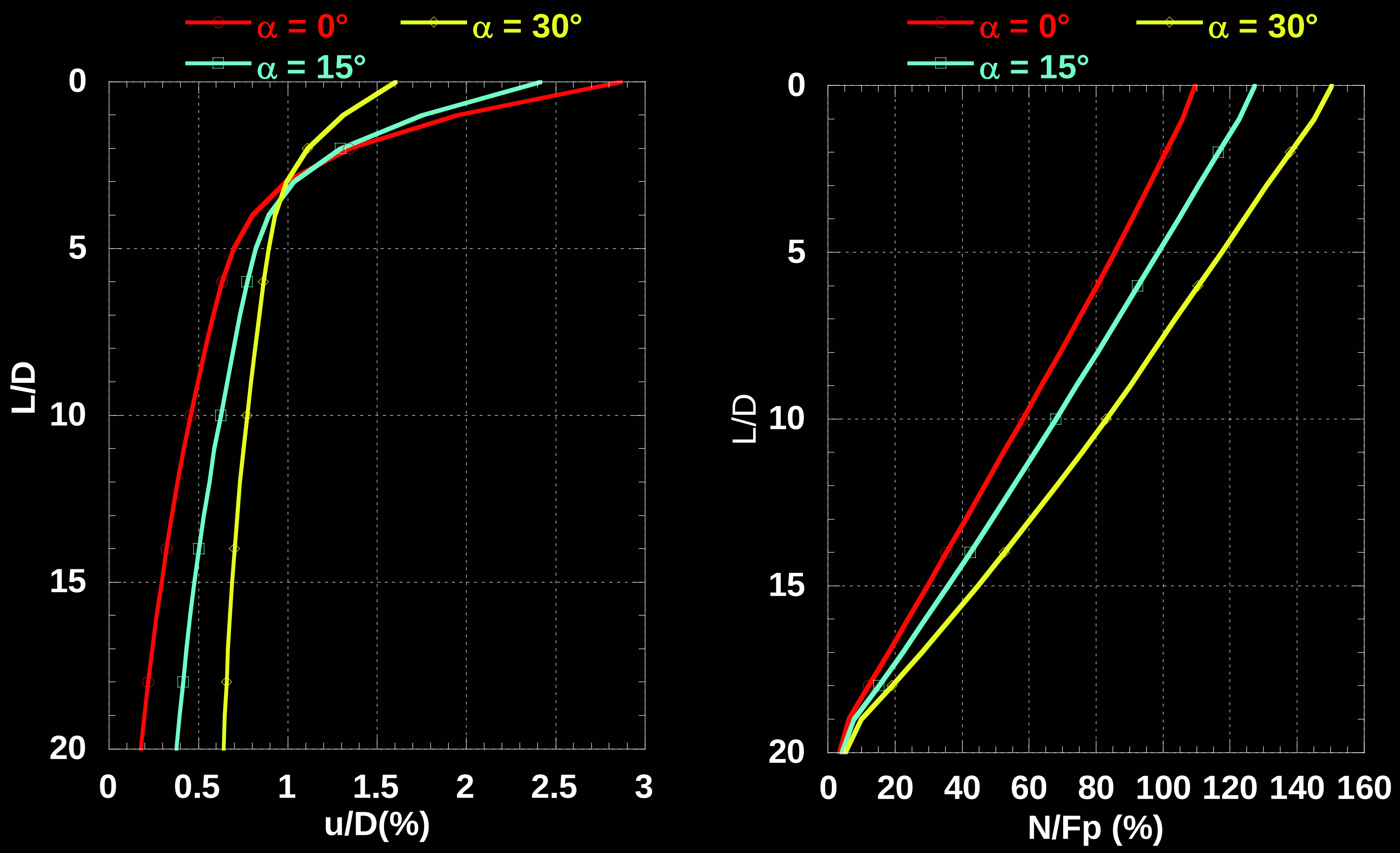
$E_{p.}I_p$ = 892,5 kN.m^2.

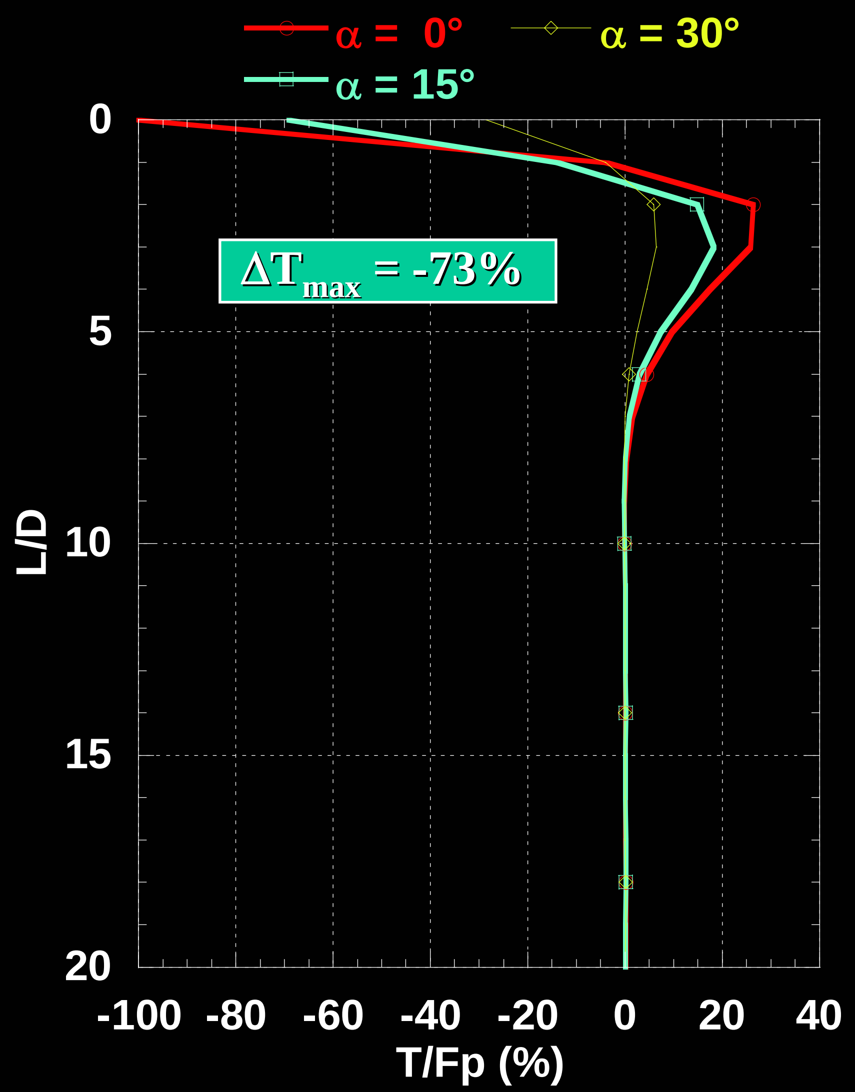
$E_{p.}A_p$ = 1155 MN

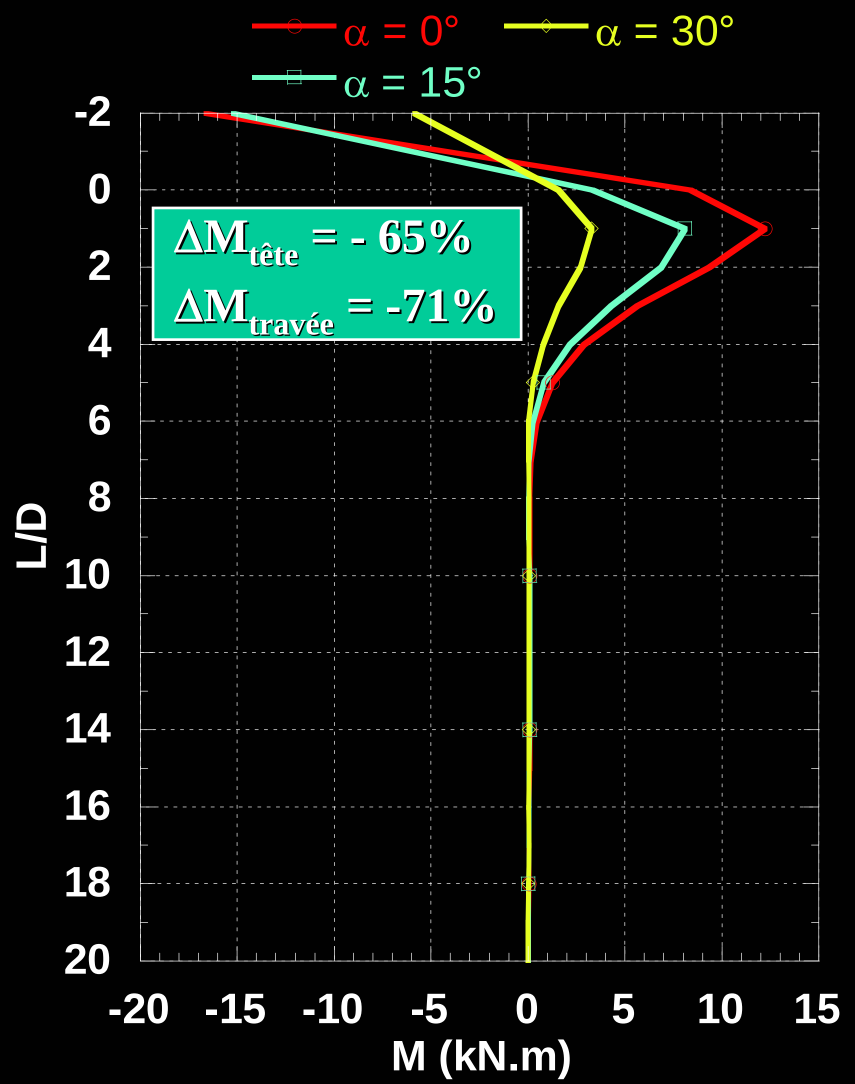
Sol

E_s = 100 MPa

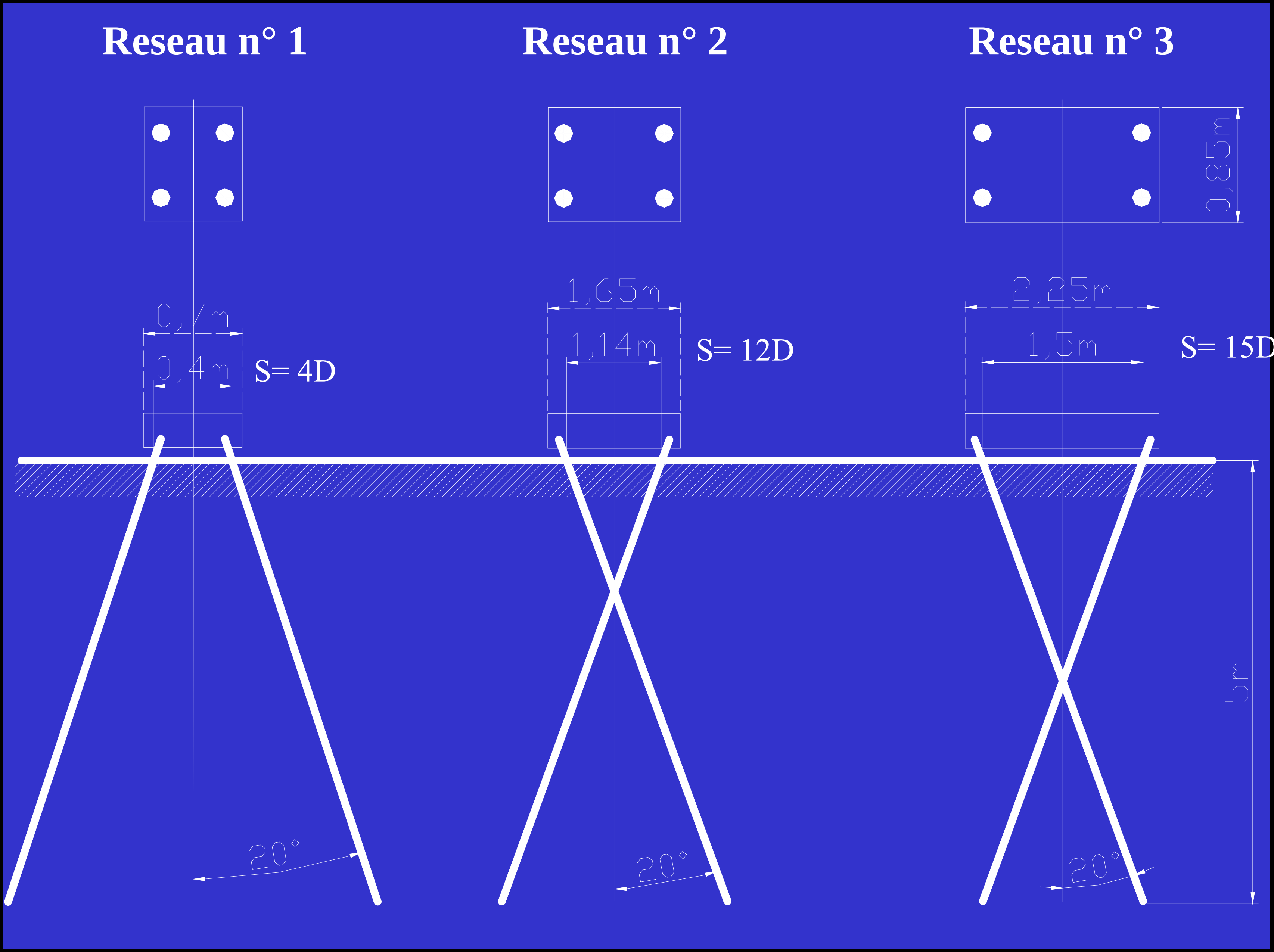
ν_s = 0,33

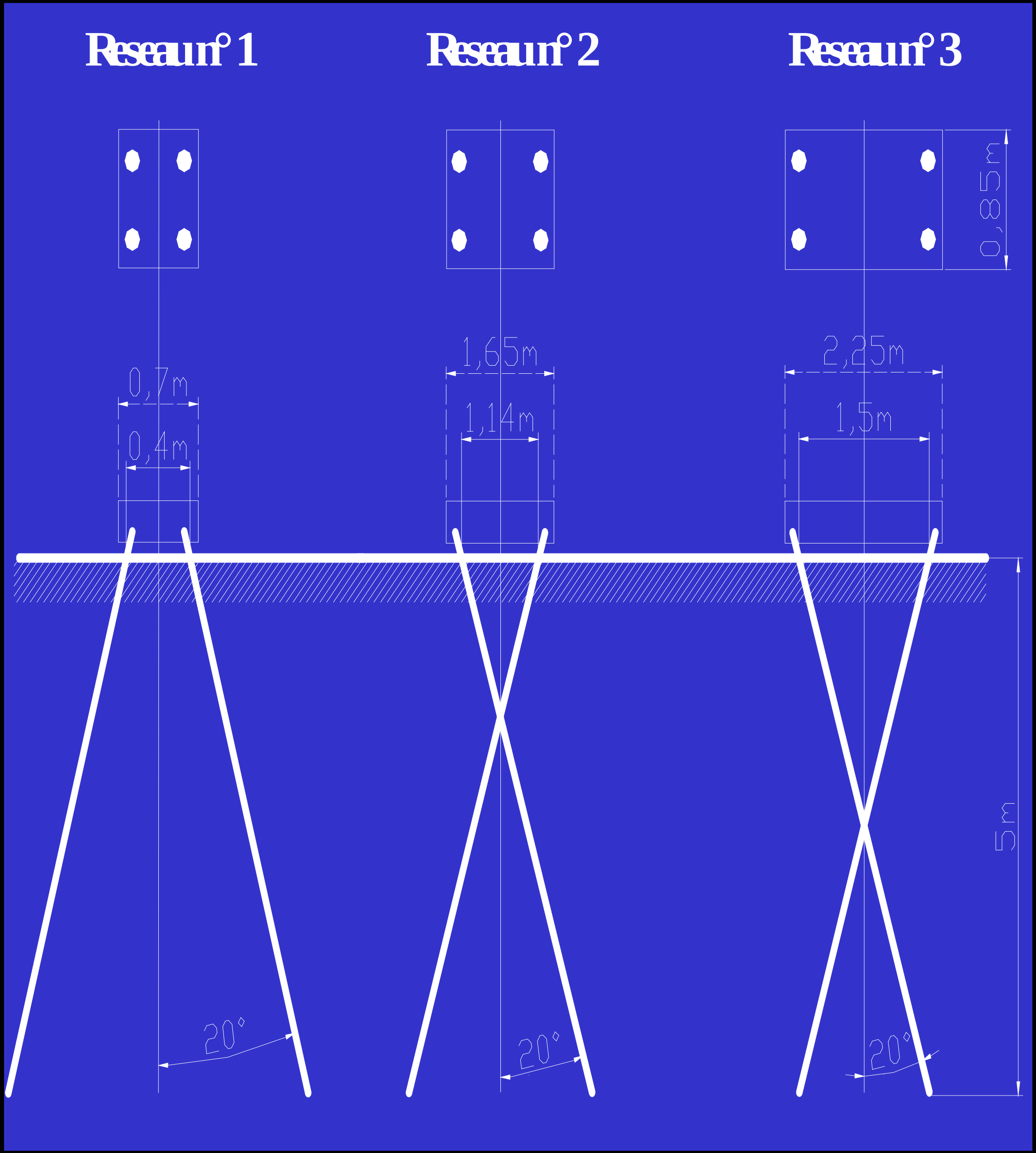

α = 0°
α = 30°
α = 15°
L/D
u/D(%)
α = 0°
α = 30°
α = 15°
L/D
N/Fp (%)


α = 0°
α = 30°
α = 15°
ΔT_{max} = -73%
L/D
0
5
10
15
20
-100 -80 -60 -40 -20 0 20 40
T/Fp (%)


α = 0°
α = 30°
α = 15°
$\Delta M_{tête}$ = - 65%
$\Delta M_{travée}$ = -71%
L/D
-2
0
2
4
6
8
10
12
14
16
18
20
-20 -15 -10 -5 0 5 10 15
M (kN.m)

ANALYSE DES ESSAIS DU CEBTP





Micropieux

Tubes 50/40 mm

D = 100 mm

$E_p.I_p = 36{,}22\ kN.m^2$

$E_p.A_p = 141{,}4\ MN$

Sol

$E_0 = 40\ MPa$

$\nu_s = 0{,}3$

C = 3 kPa

φ = 38°

ψ = 25°

Interface

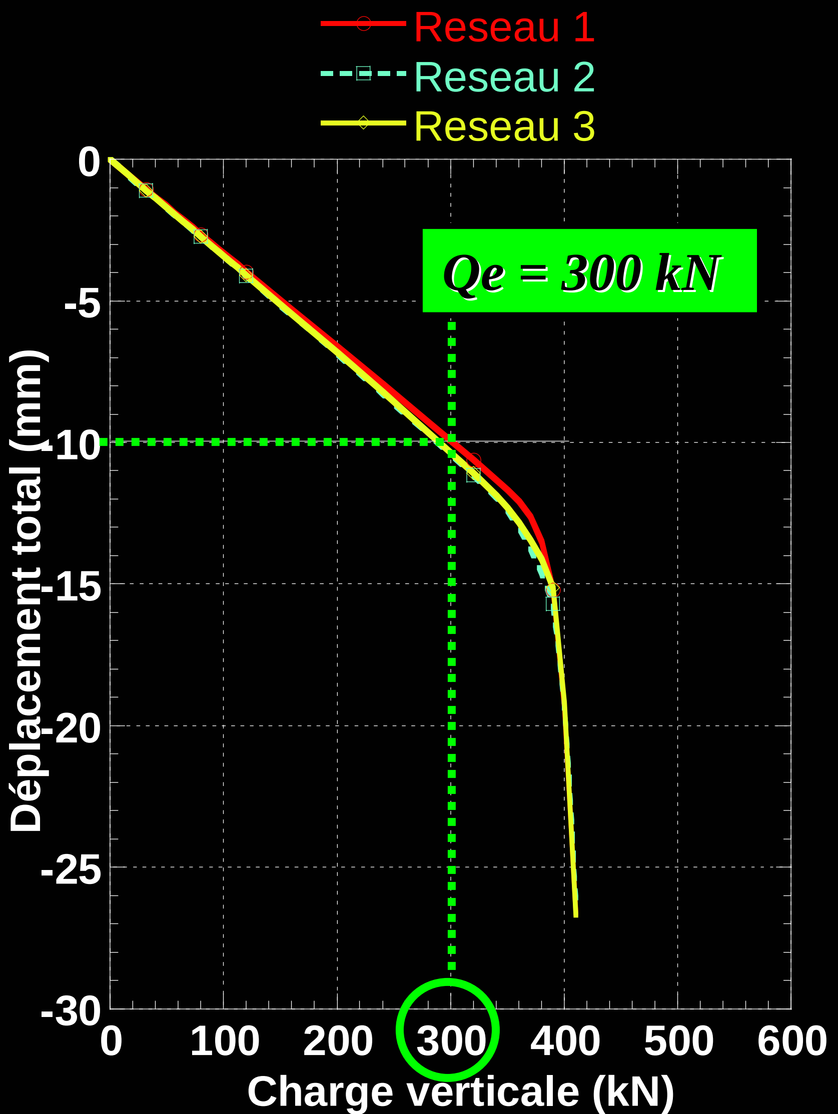
$K_t = G_s$

$K_n = 1000K_t$

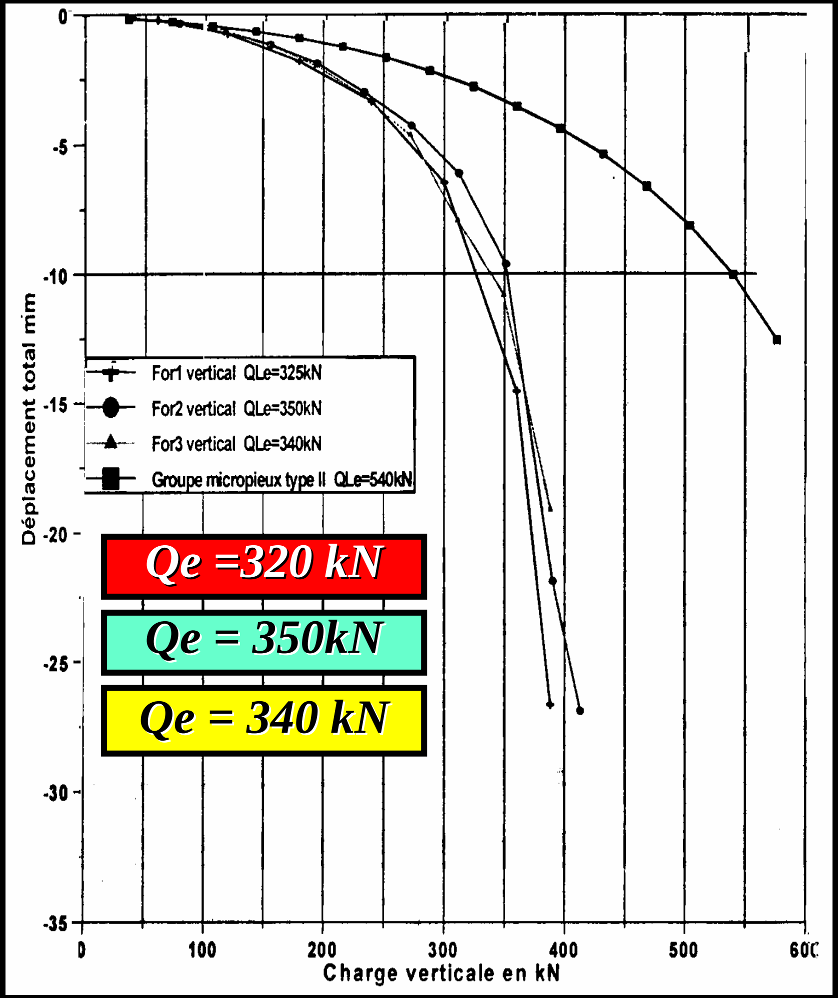
C = 60 kPa

φ =0

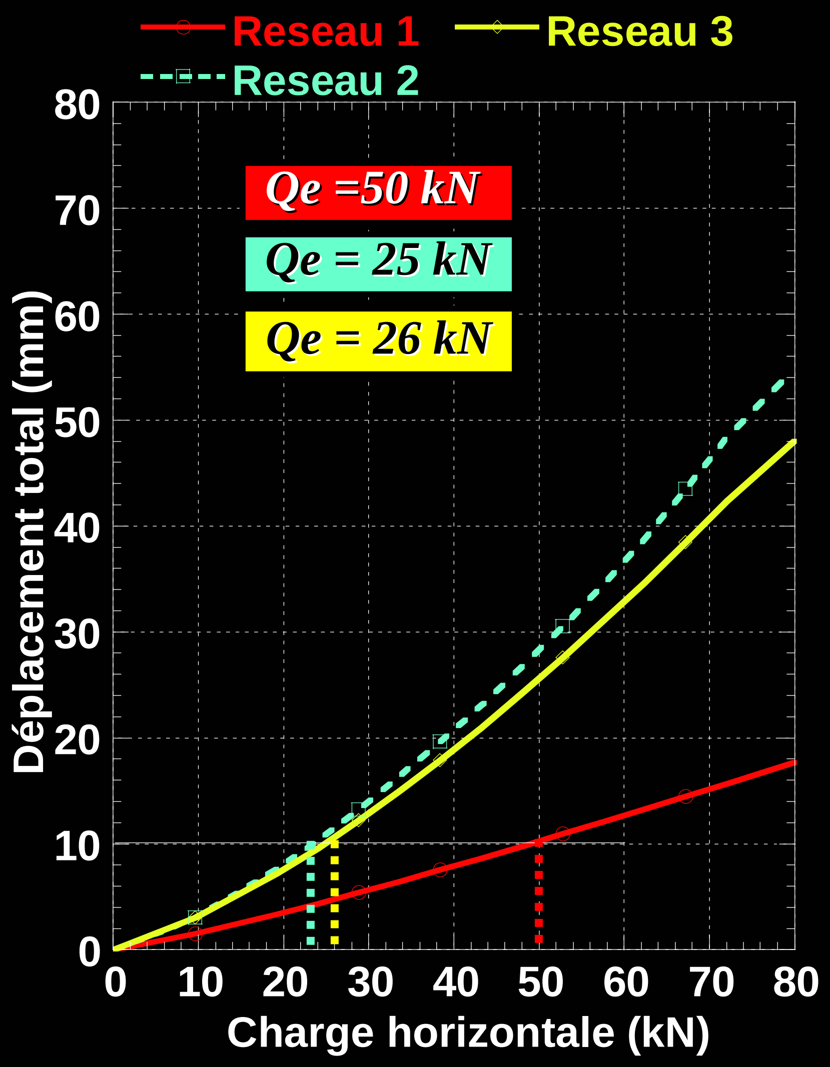
CHARGEMENT VERTICAL



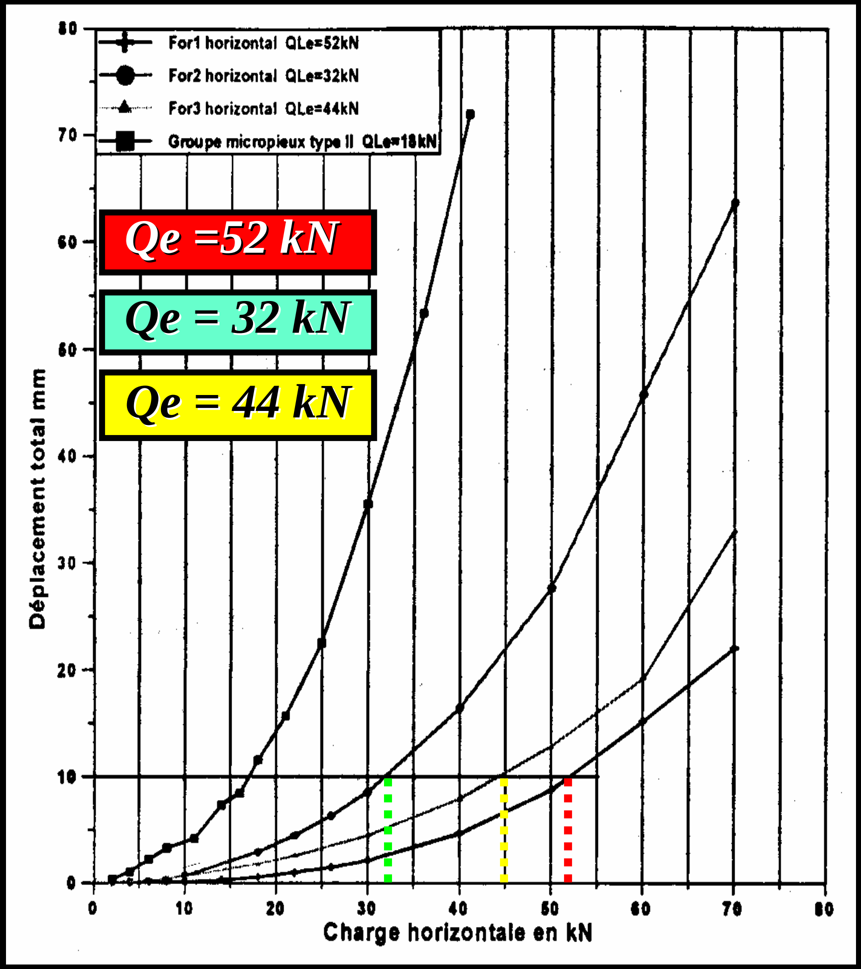
CEBTP



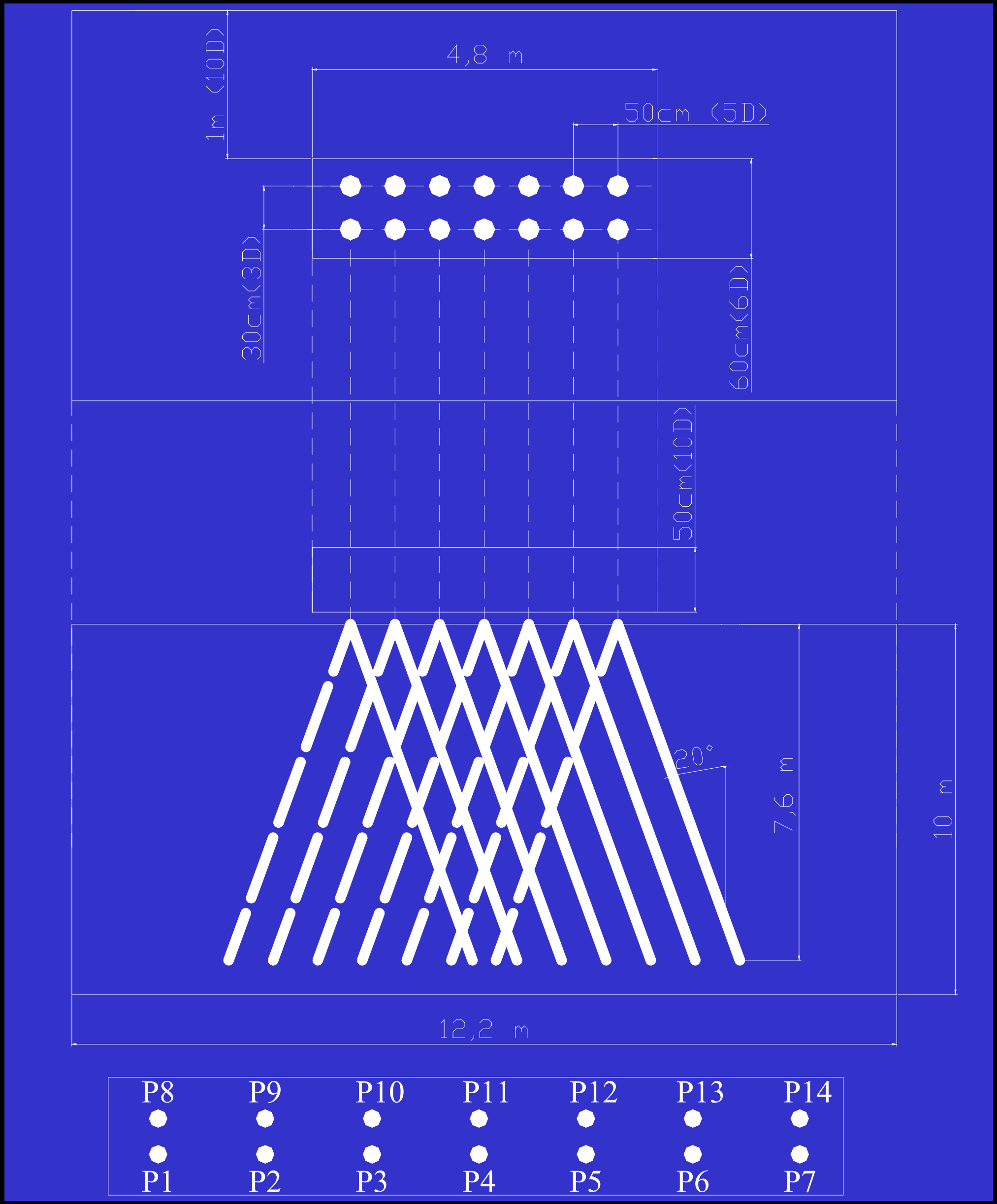
CHARGEMENT HORIZONTAL



CEBTP



RESEAU EN MUR



Micropieux

14 Tubes 50/40 mm
D = 100mm
$E_p.I_p$ = 36,22 kN.m^2
$E_p.A_p$ = 141,4 MN

Sol

E_s = 50 MPa
ν_s = 0,45

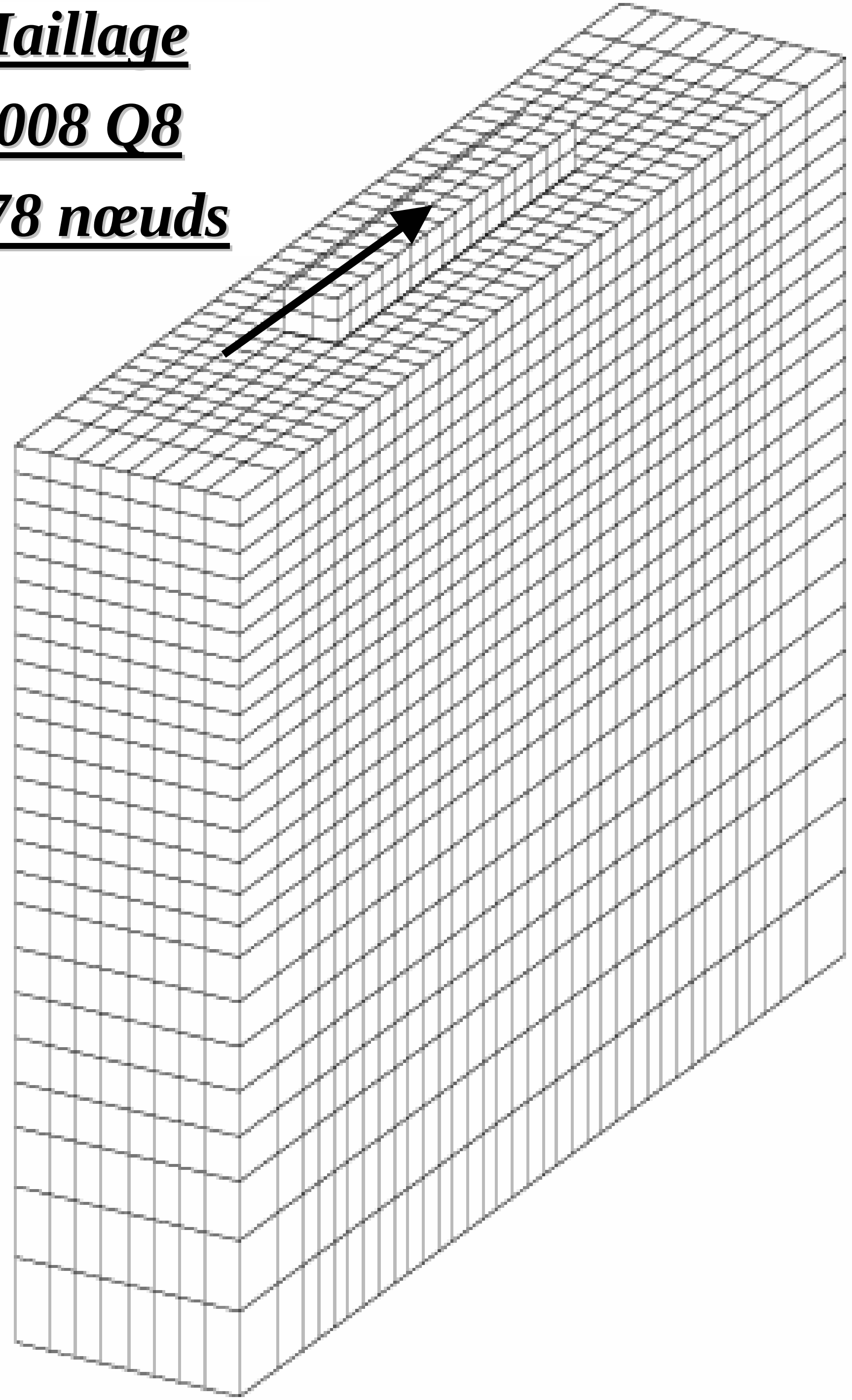
Interface

K_t = 25 MPa
K_n = 1000K_t
C = 60 kPa
φ =0

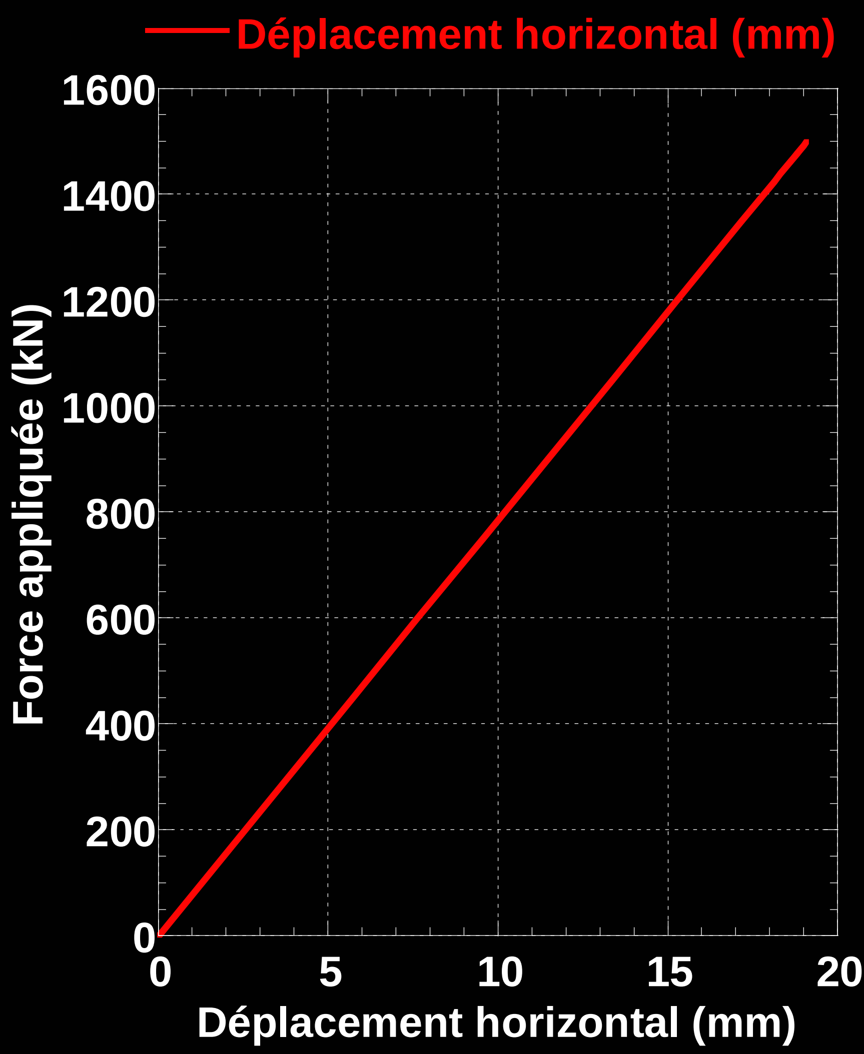
Maillage

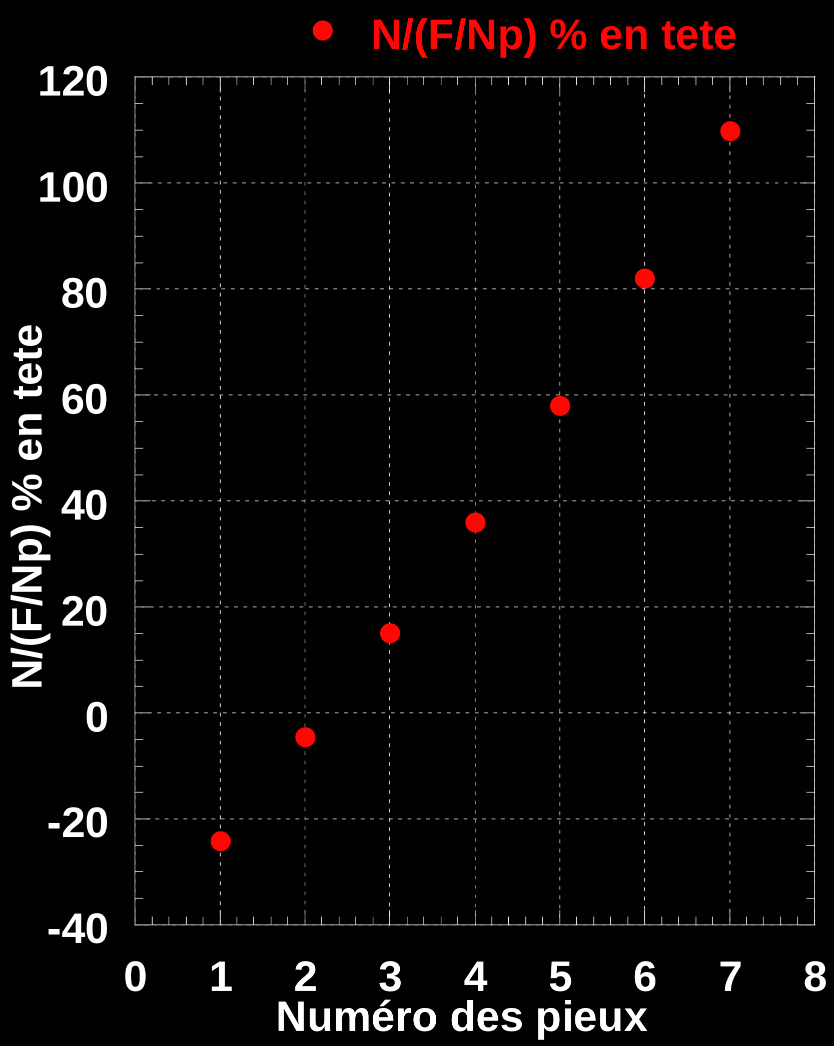
7008 Q8

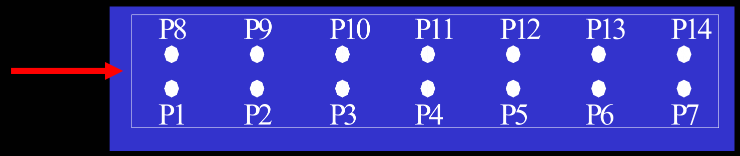
8478 nœuds



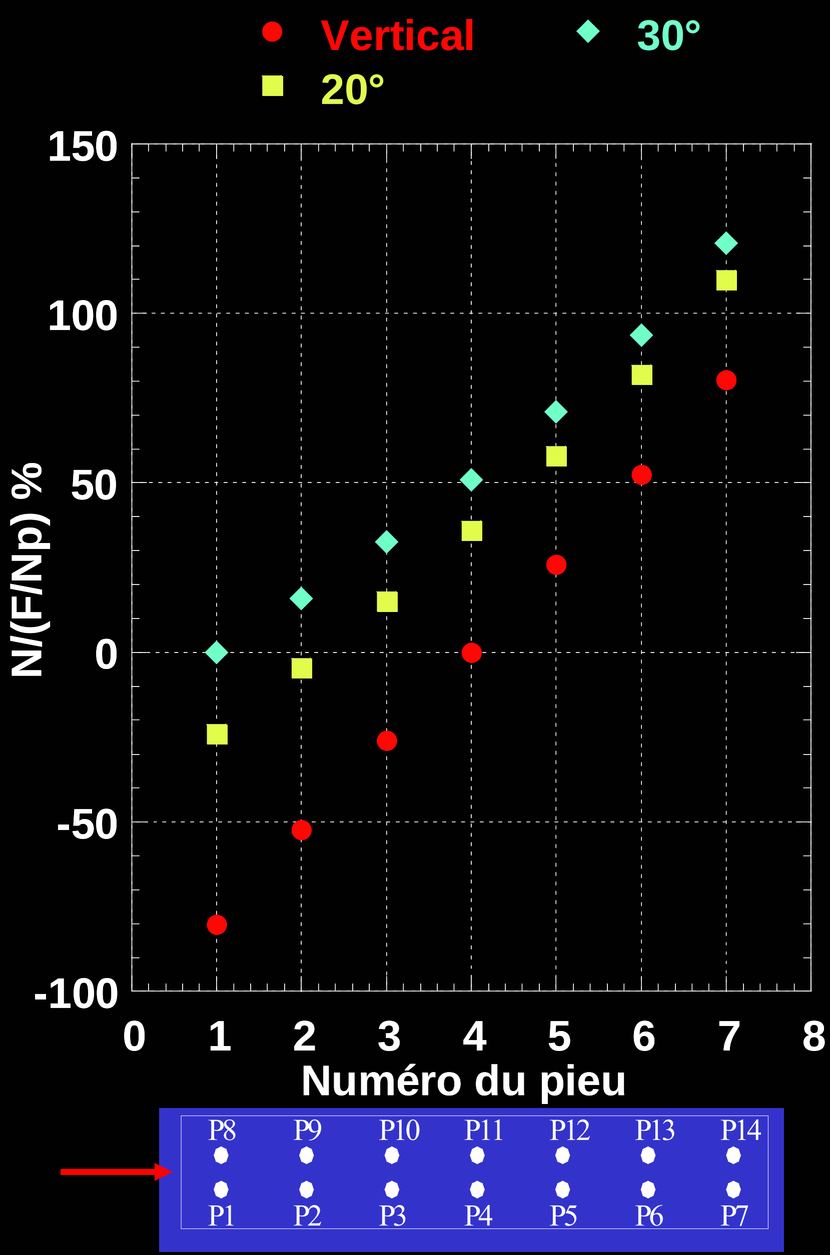
CHARGEMENT HORIZONTAL

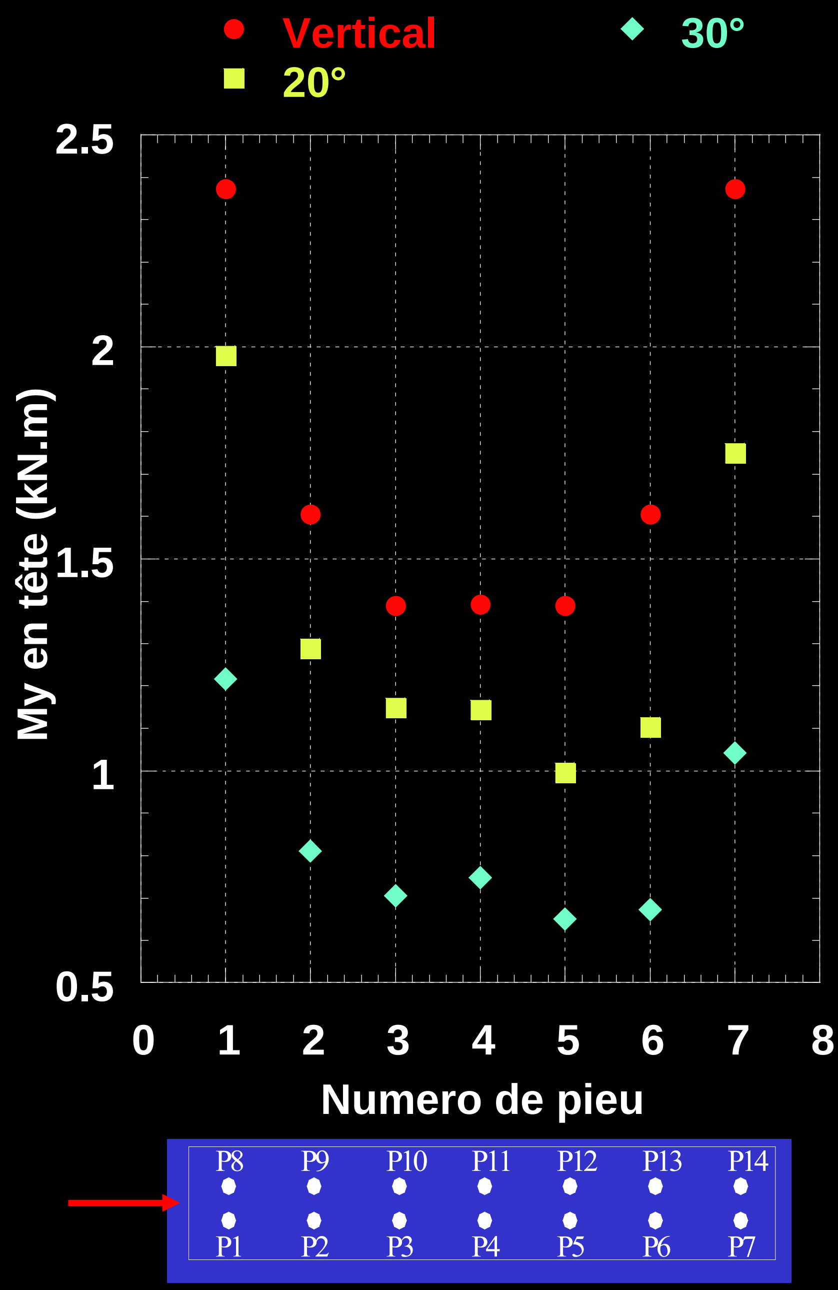






INFLUENCE DE L'INCLINAISON





Vertical
20°
30°
2.5
2
1.5
1
0.5
My en tête (kN.m)
0
1
2
3
4
5
6
7
8
Numero de pieu
P8
P9
P10
P11
P12
P13
P14
P1
P2
P3
P4
P5
P6
P7

BILAN

- **Développements :**
  - **1- Elément EPI**
  - **2-Programmation**
  - **3- Validation (numérique et expérimentale)**

- **Applications**

Aborder des géométries complexes

Influence de l'inclinaison des micropieux

PERSPECTIVES

- **Extension du modèle sous chargement sismique**