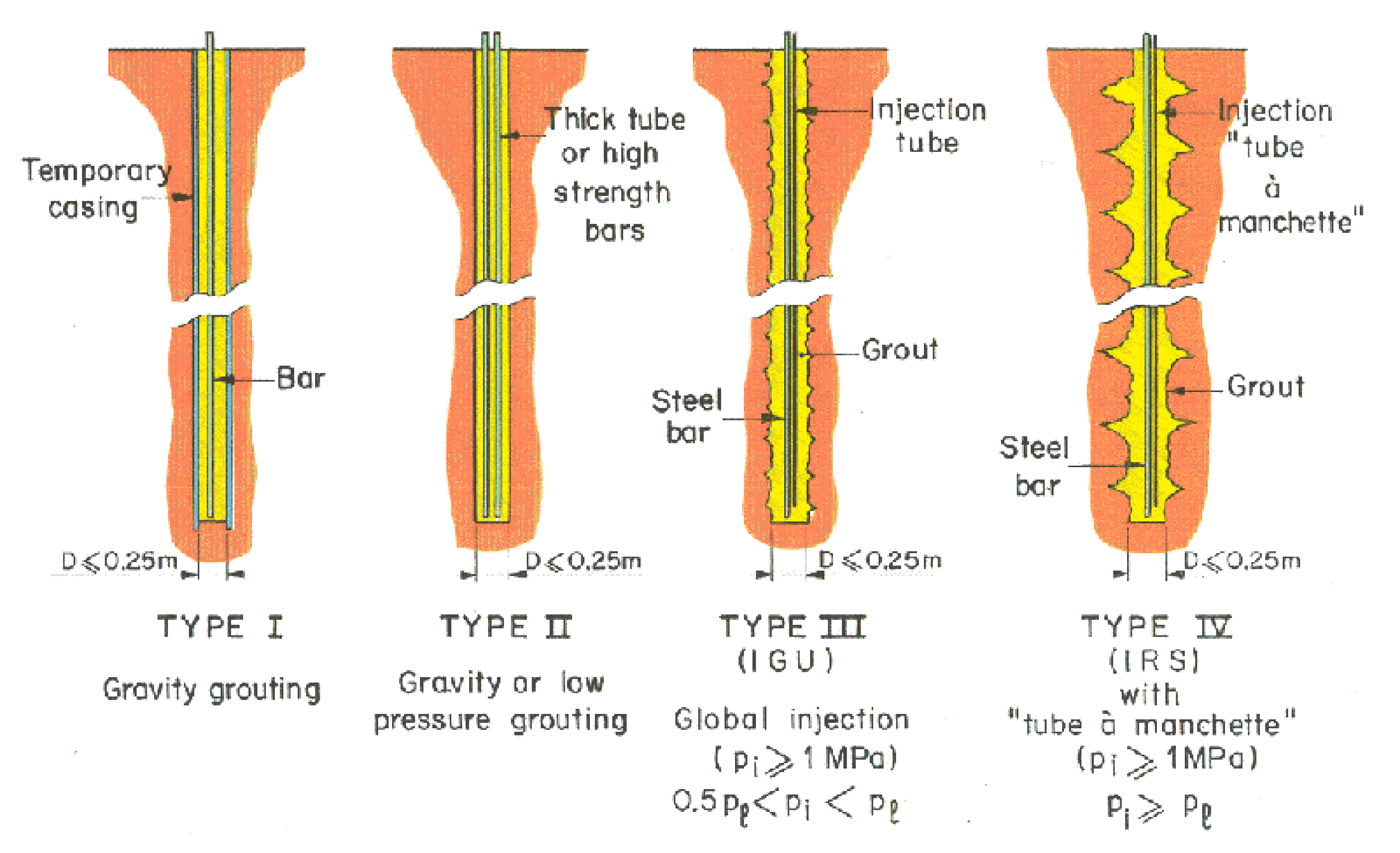
International Society for Micropiles
London, UK, 10-13 May 2009

Some lessons learnt from FOREVER the French national project on micropiles

R. Frank & F. Schlosser
Ecole des Ponts ParisTech

- classification of micropiles in France
- the French National Project FOREVER (1993-2001)

Classification of bored micropiles



FOREVER

The French National Project

Soil reinforcement by micropiles

Chairman : Henri CYNA

Scientific and technical directors:

François SCHLOSSER and Roger FRANK

Supported by Réseau Génie Civil et Urbain (Ministères Equipement + Recherche)

1993-2001

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Institut pour la recherche appliquée et l'expérimentation en génie civil

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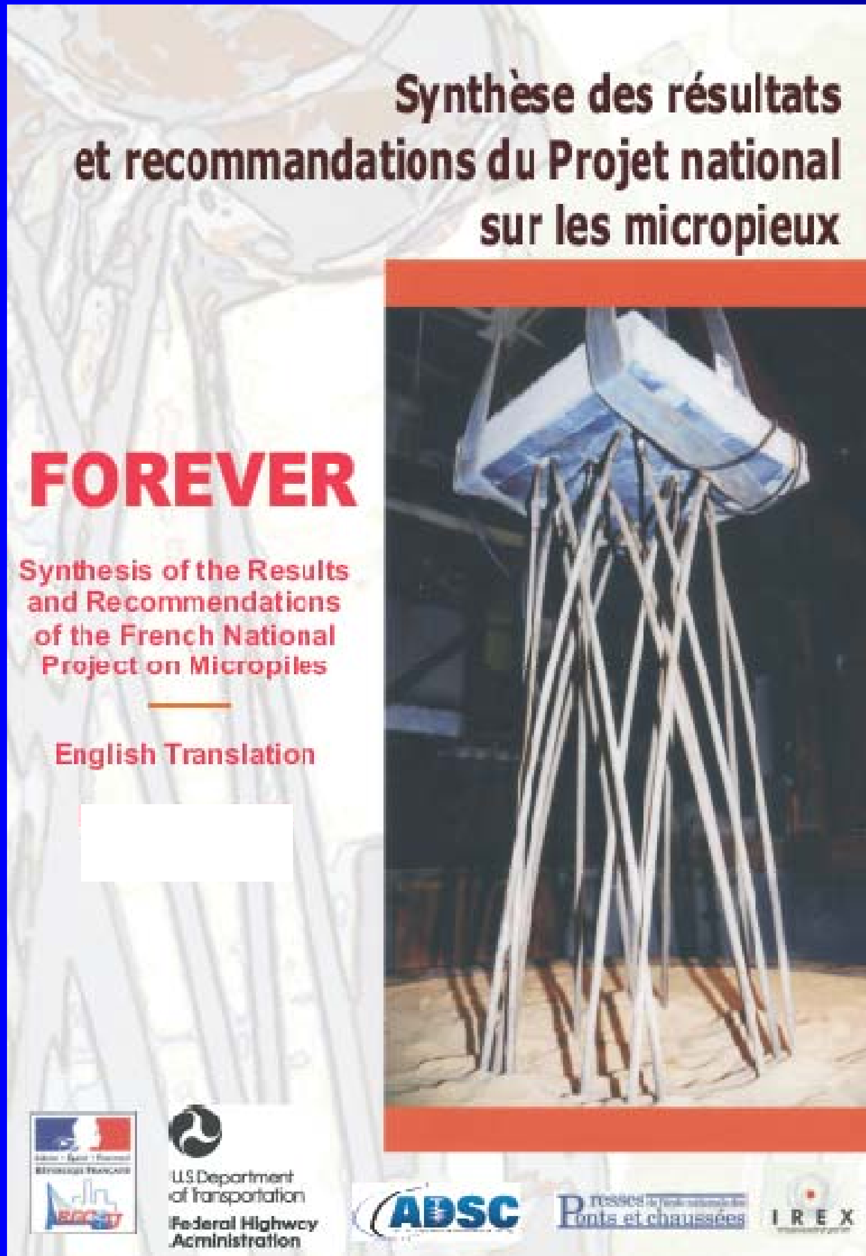
Fundings

French ministries (15%)	764 000 €
French partners (71%)	3 614 000 €
F.H.W.A Contribution (14%)	713 000 €
Total budget	5 091 000 €

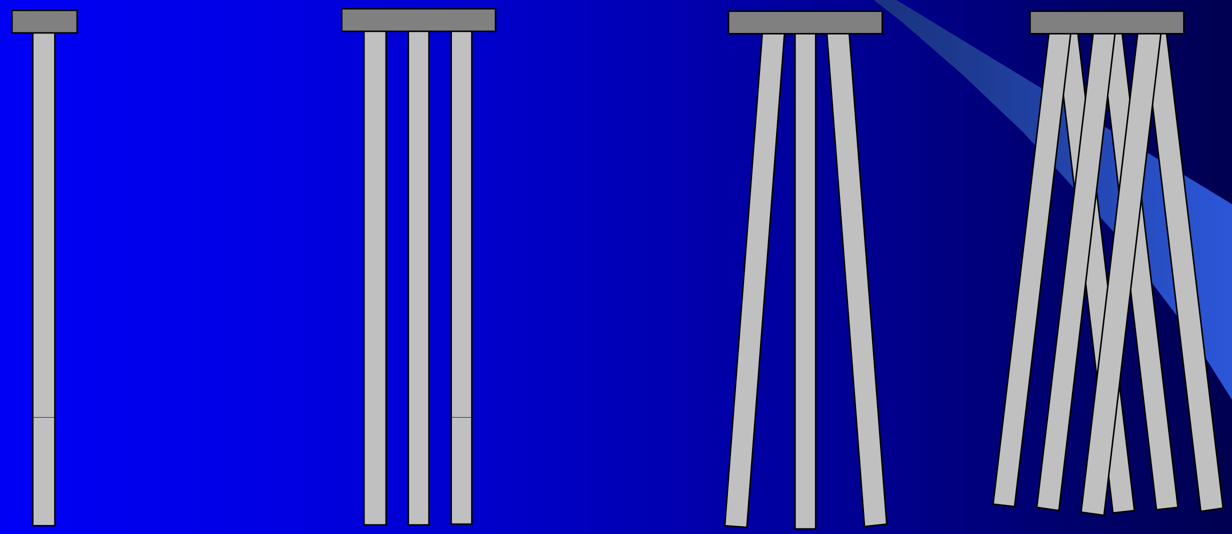


Published in 2004
English version 2008

FOREVER

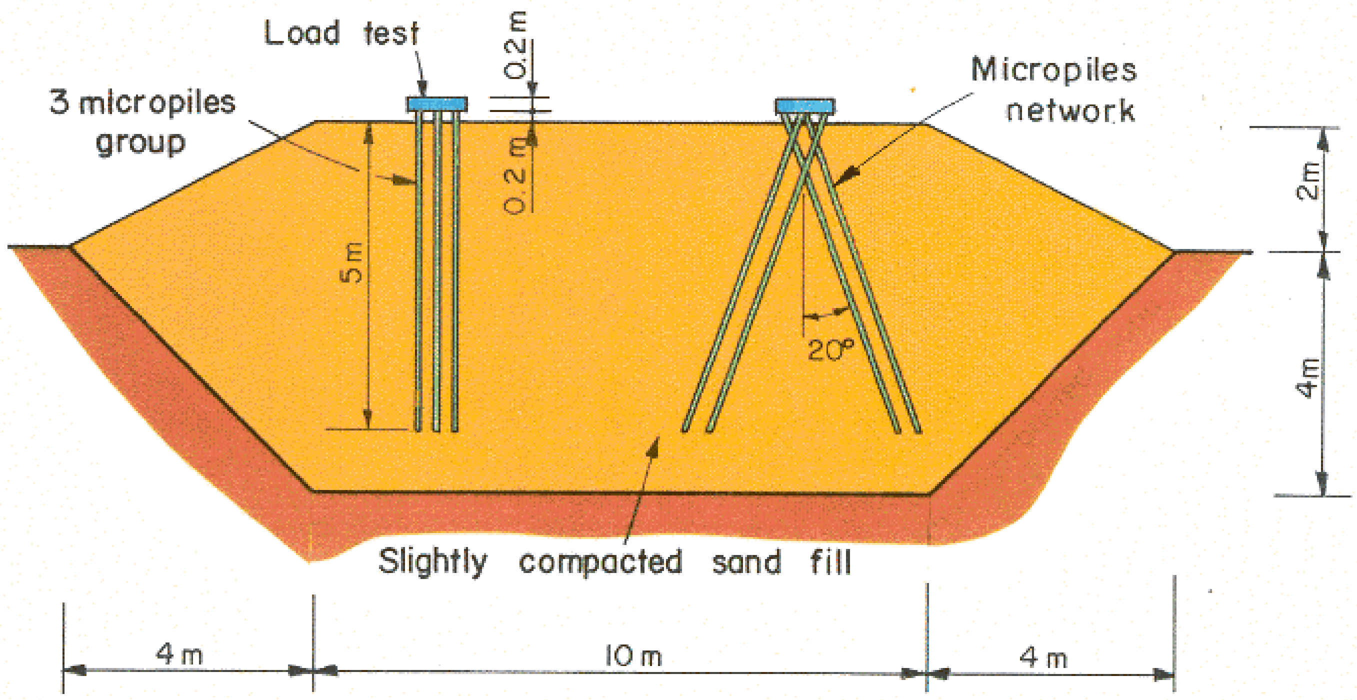
- Experimental tools
- Main results :
  - isolated micropiles
  - groups
  - networks
- Numerical method for displacement calculation (GOUPEG method)

DEFINITIONS



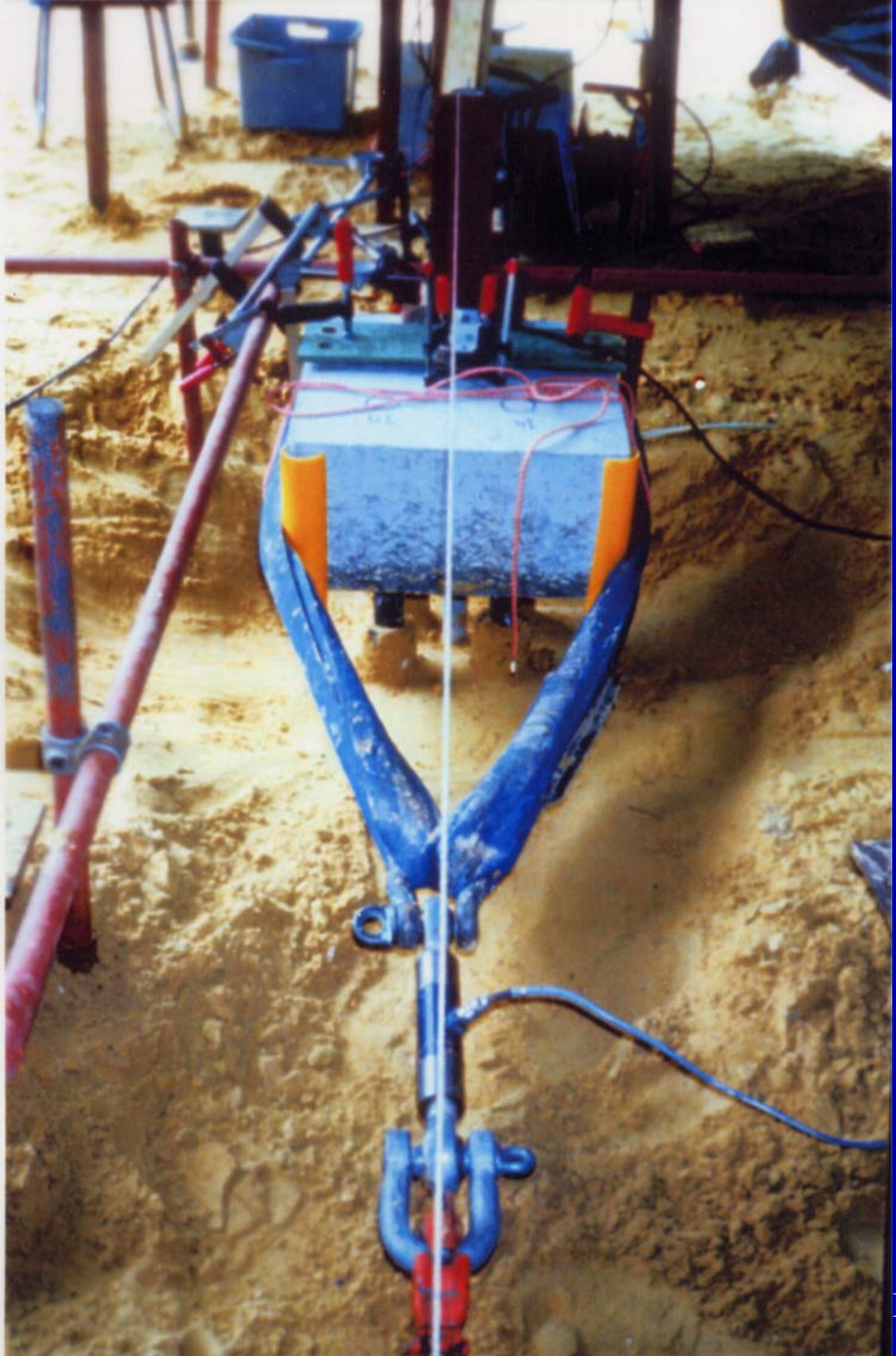
ISOLATED MICROPILE	GROUP of MICROPILES	NETWORKS of MICROPILES: "ELEMENTARY" or "RETICULATED"

Experimental site of CEBTP at St Rémy-lès-Chevreuse



FOREVER - MICROPILES

(Cross-section of the experimental site)



Horizontal loading test of an A-shaped (double easel) micropile network

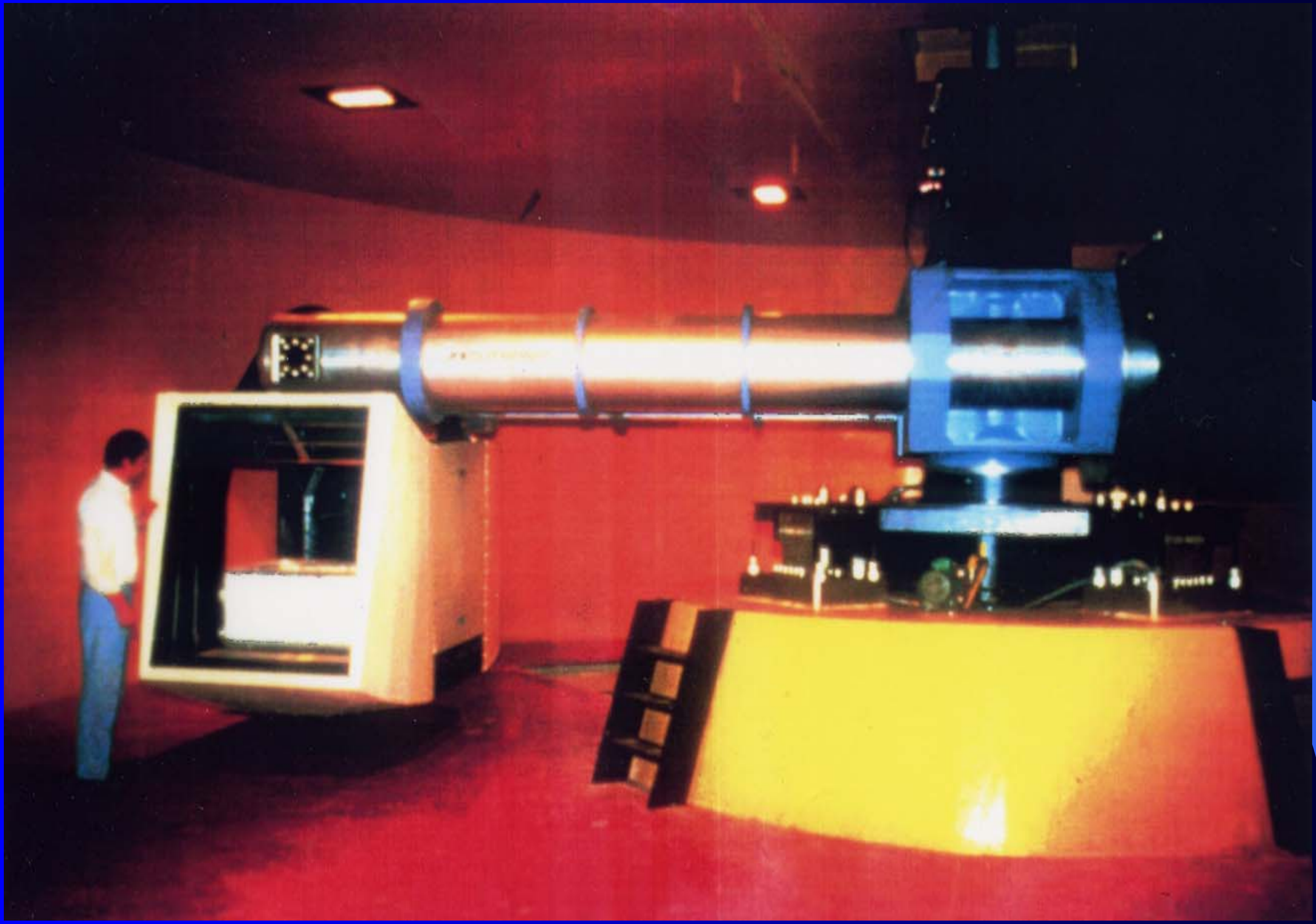
Main type of micropile tested at the FOREVER experimental site:

- *Fontainebleau sand (I_D = 0.5)*
- *Boring, Grouting by gravity (Type II)*

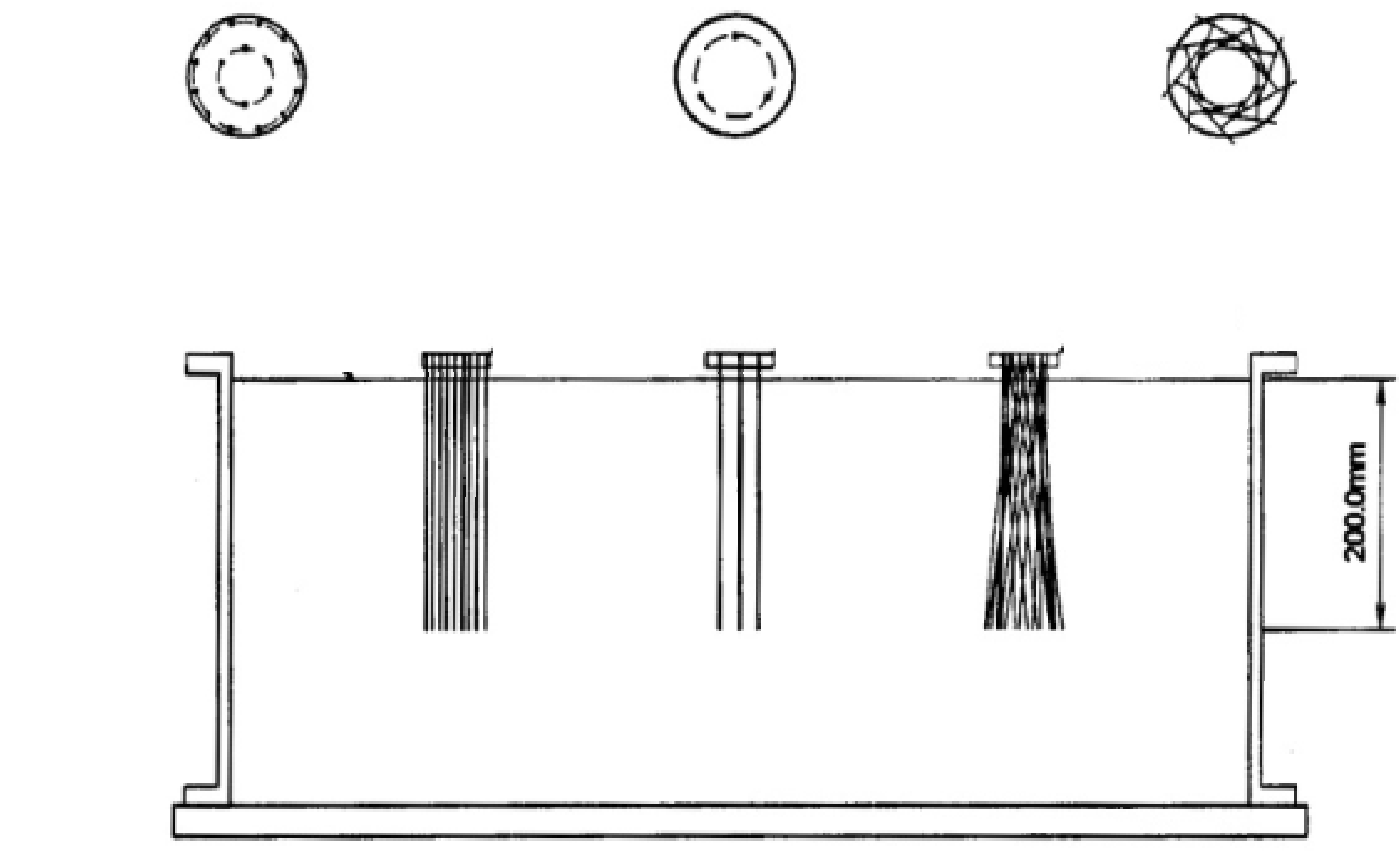
  II_a : complementary grouting from the top

  II_b : complementary grouting from the bottom
- R-SOL *(Type IV)*
- *Main parameter : q_s (limit shaft friction)*

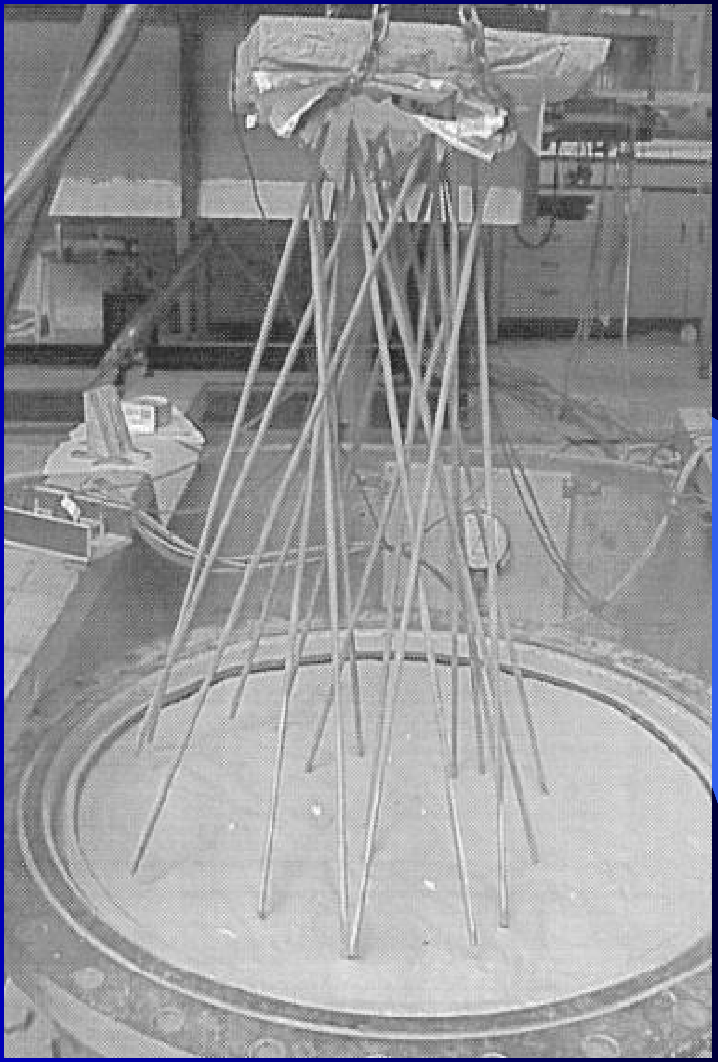
LCPC Centrifuge (Nantes)



Lizzi's models in the centrifuge

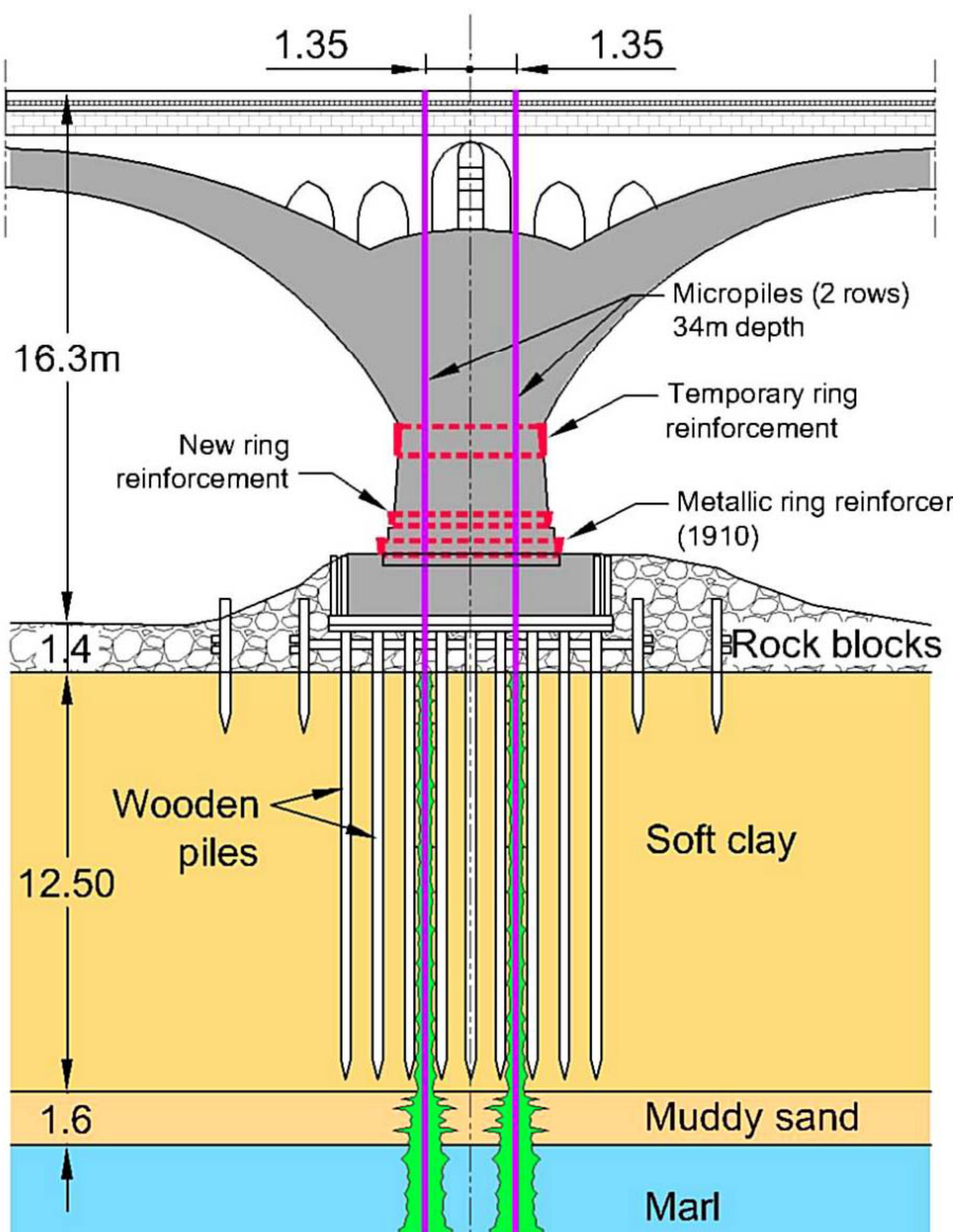


Reduced scale models (L = 2 m) of groups and networks in the experimental tank at Labo 3S (Grenoble)



Calibration chamber of CERMES

FOUNDATION REINFORCEMENT OF THE PIERRE BRIDGE IN BORDEAUX



Movement of the water level
(sea tide, river flow)

Wooden piles :

B = 0,30 m   s/B = 4

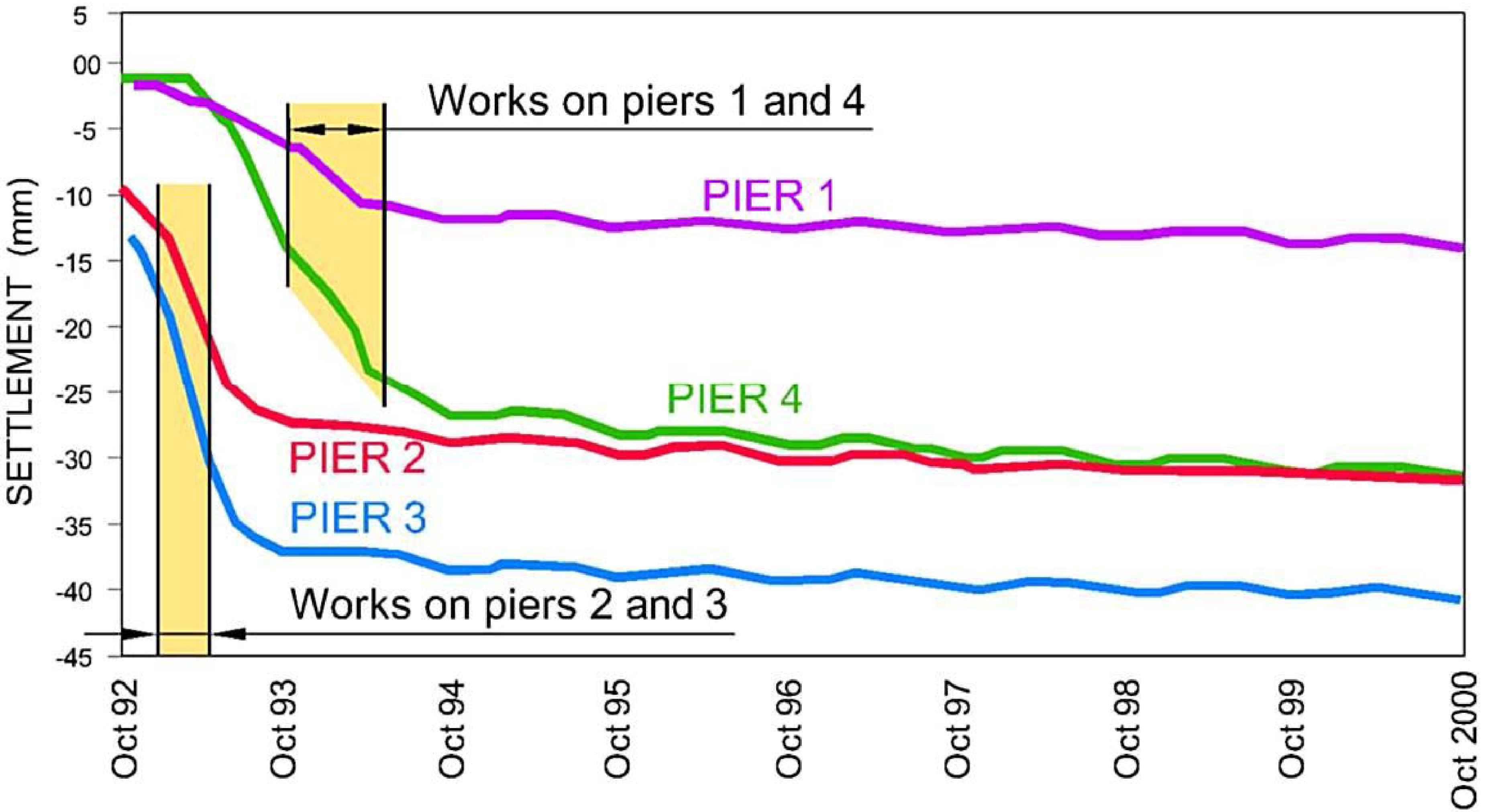
Micropiles :

B = 0,22 m   s/B = 10

MICROPILES :

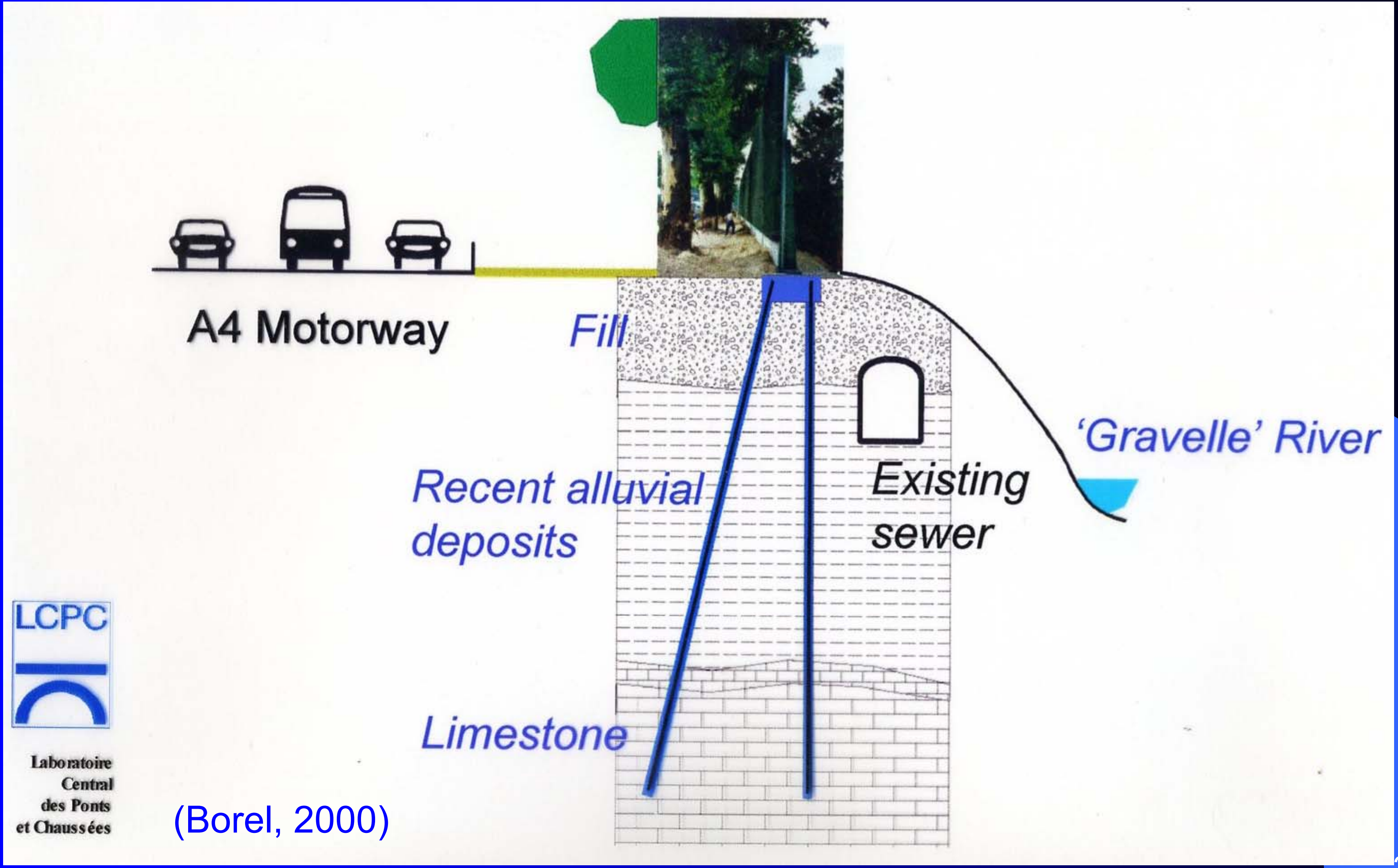
- Bored micropiles
- Reinforced tube (178/154 mm)
- Type IV (injection with “tube à manchettes”) in the marl
- Type II (global injection at low pressure) in the masonry
- Measured load transfer 5 to 20 %

STABILIZATION OF THE SETTLEMENTS AFTER MICROPILES INSTALLATION



Rueil-Malmaison tests

New foundations of buildings and structures : St Maurice anti-noise wall



(Borel, 2000)

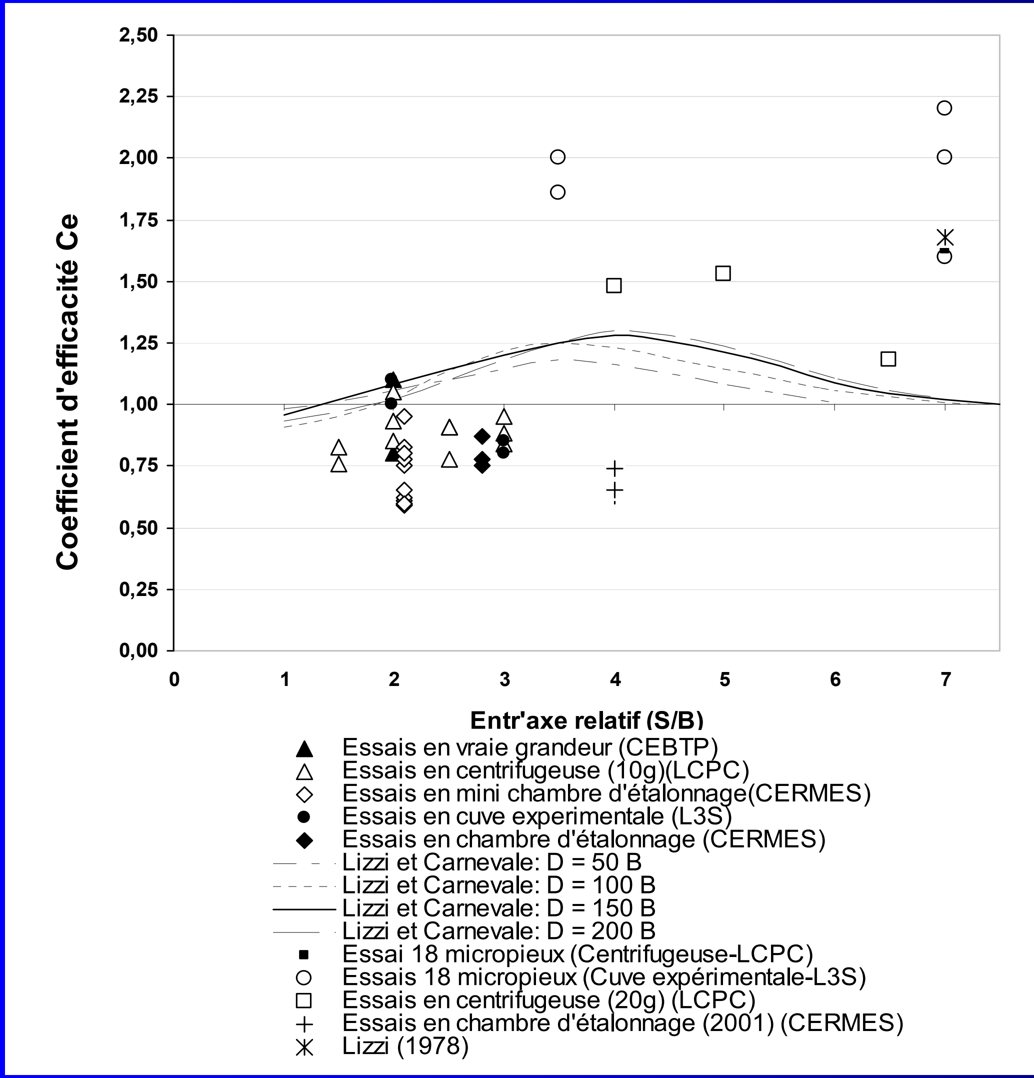
Isolated micropiles : Comparative Results

Soil	Micropile type	p_l (MPa)	q_s (kPa) measured	q_s (kPa) Bustamante&Doix chart
Fontainebleau loose sand (Forever)	II_h II_b IV (R-Sol) IV(Ischebeck)	0.4 0.4 0.4 0.4	52 52 72 72	45 – 50 45 – 50 90 – 100 90 – 100
Loose clayey sand (Saint Etienne)	IV	1.3	375	180
Sand and gravel Weathered clay (Rueil)	II II	3.8 1.8	225 135	375 200

GROUP RESULTS

Organisme	Type d'essai	N	Mise en place	Entr'axe	D	B	I_D	Coefficient d'efficacité
				S/B	m	cm		
CEBTP	Vraie grandeur sur site	4	Forage	2	5	10	0,57	0,8 <Ce< 1,1
LCPC	Centrifugeuse à 10 g	3	Fonçage	1,5 à 3	0,5	1,2	0,65	0,76 <Ce< 1,05
LCPC	Centrifugeuse à 20 g	9 à 36	Fonçage	4 à 10	0,25	6	0,57	1,18 <Ce< 1,53
LCPC	Centrifugeuse à 10 g	18	Moulés	7	0,2	0.2	0,8	1,56 et 1,61
L3S	Cuve expérimentale	4	Fonçage	2 et 3	1,5	2,5	0,5	0,8 <Ce< 1,1
L3S	Cuve expérimentale	18	Fonçage	3,5 et 7	1	2	0,45 / 0,5	1,6 <Ce< 2,2
CERMES	Mini chambre d'étalonnage	5	Fonçage	2,1	0,2	1,12	0, 36 / 0,50 / 0,76	0,59 <Ce< 0,95
CERMES	Chambre d'étalonnage	5	Fonçage	2,8	0,5	2	0,45 / 0,55 / 0,8	0,75 <Ce< 0,87
CERMES (2001)	Chambre d'étalonnage	5	Fonçage	4	0,5	1	0,55	0,63 <Ce< 0,74
Lizzi (1978)	Cuve expérimentale	18	Moulage	7	2	2	?	1,68

Interpretation



Do we have a positive *group* effect ($C_e > 1$)

?

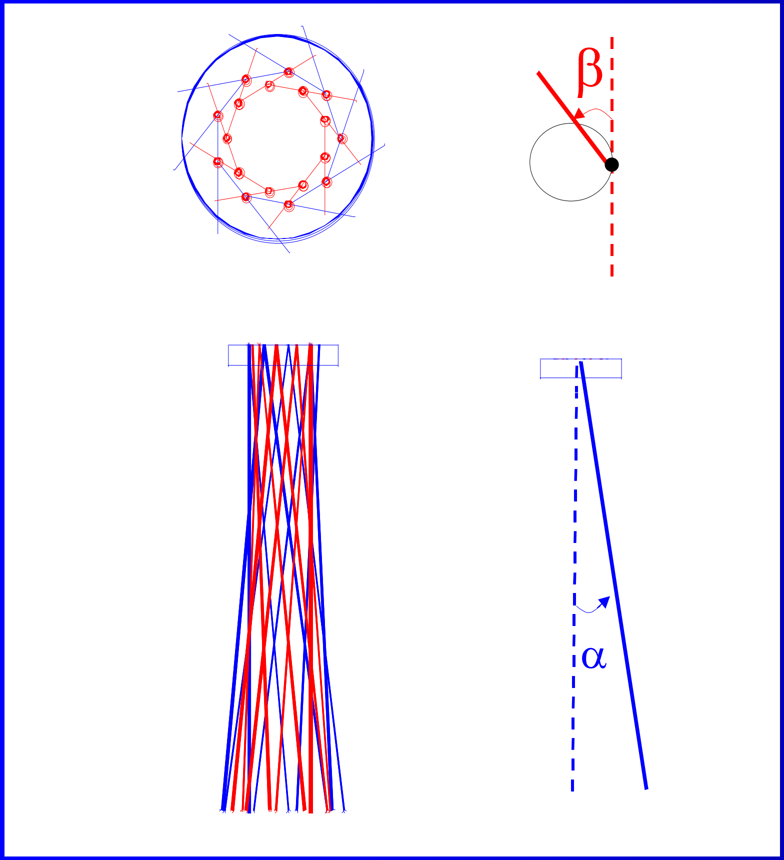
Interpretation

Positive group effect

Slenderness ratio	*D/B > 50*
Number of micropiles	*large N*
Density	$I_D < 0,50$
Installation order	*central inclusion last installed*

Networks : interpretation

New parameter :angle of interlocking



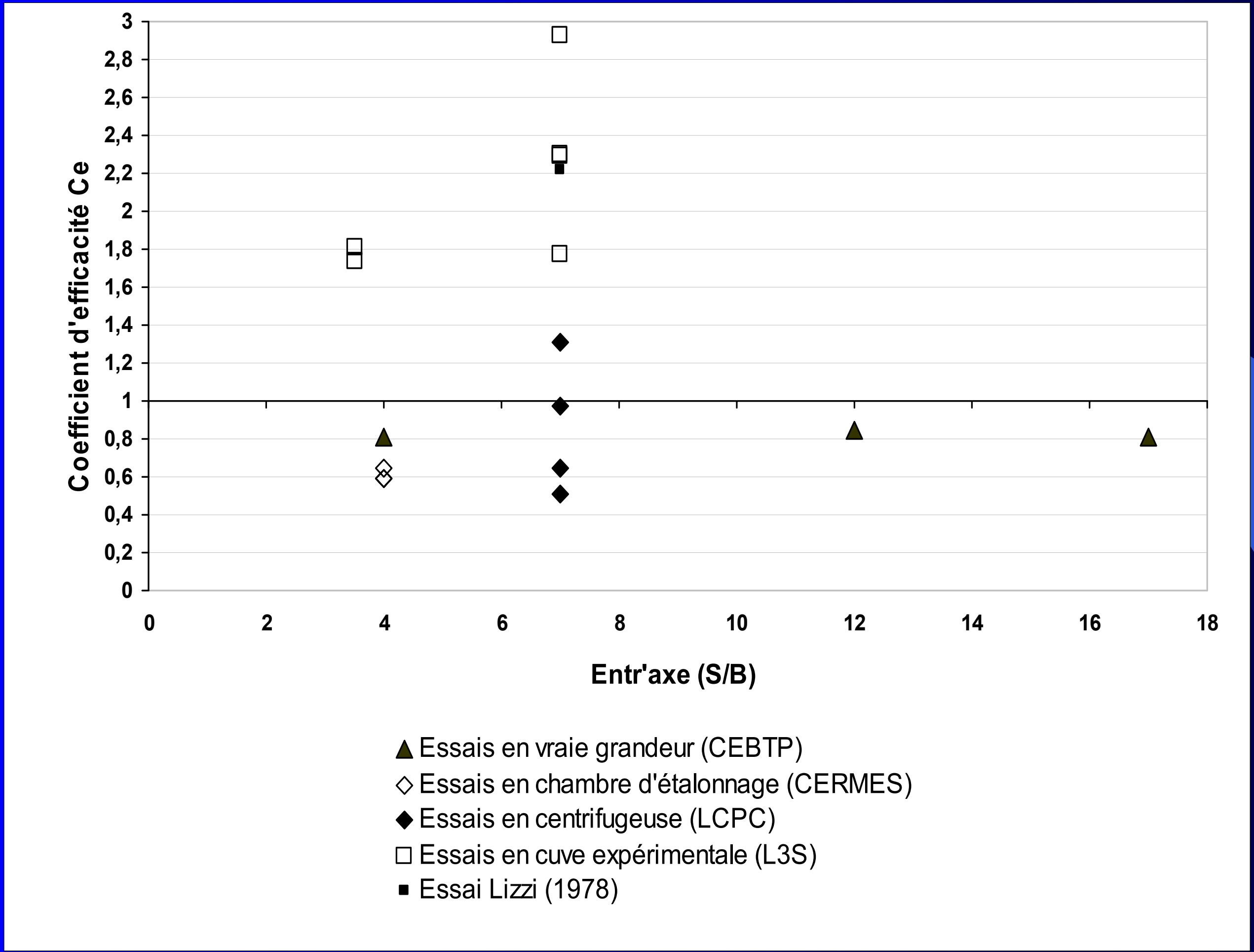
β interlocking angle

α inclination angle

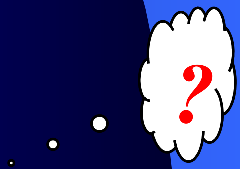
NETWORK RESULTS

Labo	Essai	Mise en place	N	α	β	S/B	B mm	D m	C_e
CEBTP (2D) Vraie grandeur	Réseau 1	Forage	4	20°	-	4	100	5	**0,81**
	Réseau 2	Forage	4	20°	-	12	100	5	**0,85**
	Réseau 3	Forage	4	20°	-	17	100	5	**0,81**
LCPC Centrifugeuse à 10g	Type Lizzi (initial)	Moulé	18	9°* / 11,8°**	-20°* / 200°**	7	2	0,2	**1,31**
	Divergent	Moulé	18	9°	90°	7	2	0,2	**0,97**
	En vrille	Moulé	18	9°	0°	7	2	0,2	**0,65**
	Alterné	Moulé	18	9°	0°*/180°**	7	2	0,2	**0,51**
LCPC Centrifugeuse à 10g	Chevalet 1	Fonçage	2	10°	-	3	12	0,6	**0,92[1]**
	Chevalet 2	Fonçage	2	20°	-	3	12	0,6	**0,87[1]**
L3S Cuve expérimentale	1998 (2)	Fonçage	18	20°	0° */ 180°**	7	10	1	**2,3**
	1998 (3)	Fonçage	18	20°	0° */ 180°**	3,5	10	1	**1,81**
	1999 (2)	Fonçage	18	20°	0° */ 180°**	7	10	1	**1,77**
	1999 (3)	Fonçage	18	20°	0° */ 180°**	3,5	10	1	**1,74**
	1999 (4) plus enchevêtré	Fonçage	18	20°	-40° ou 220°***	7	10	1	**2,29**
	2001 (1) quasi cylindrique	Fonçage	18	20°	≈ -30° / 210° **	7	10	1	**2,93**
CERMES Chambre d'étalonnage	En surface	Fonçage	5	15°	90°	4	10	0,5	**-**
	σ_C = 50 kPa	Fonçage	5	15°	90°	4	10	0,5	**0,65**
	σ_C = 100 kPa	Fonçage	5	15°	90°	4	10	0,5	**0,59**
	σ_C = 150 kPa	Fonçage	5	15°	90°	4	10	0,5	**0,59**
Lizzi (1978) Cuve expérimentale		Moulé	18	8,3°* / 11,8°**	-20°* / 200°**	7	20	2	**2,22**

Interpretation



Do we have a positive *network* effect ($C_e > 1$)

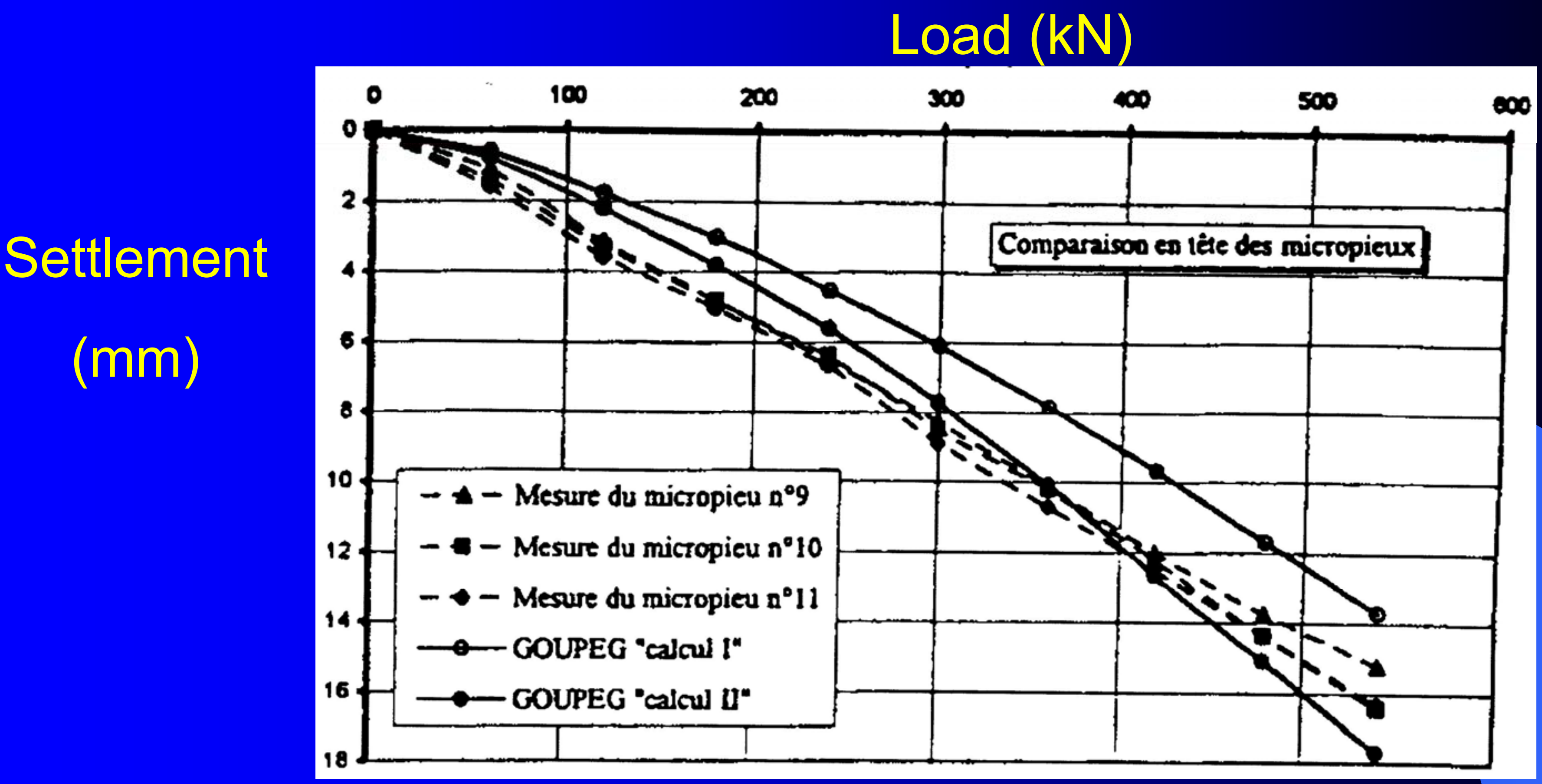


Interpretation

Positive network effect

Slenderness ratio	*D/B>50*
Number of micropiles	*N important*
Densité	$I_D<0,50$
Interlocking	β *ensures good interlocking*
Inclination	*Development of passive pressures*

Numerical method for displacement calculation (GOUPEG 'hybrid' pt-z and p-y method)



Comparison between measured and calculated load - settlement curves of the micropiles of the group

General conclusions

1) Great influence of the installation method, which is difficult to quantify

2) Type 3 or 4 micropiles should be treated in a different manner from type 1 or 2

3) Group effect is obtained : both for vertical and horizontal loadings

4) Network effect : obtained for horizontal loadings, but not very clear for vertical loadings

5) The hybrid model approach (e. g. GOUPEG software) is well adapted to the SLS calculations of micropile groups and networks

Other conclusions

(Not developed today)

5) Dynamic tests seem to provide a reliable quality control method

6) Seismic behaviour of inclined micropiles is more efficient than vertical micropiles

Thank you for your attention !

Acknowledgments :

République Française

RGCU

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