LCPC Laboratoire Central des Ponts et Chaussées

QUAKER program
Topic B1 : inclined piles under seismic loads

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- Quaker program Topic B1 : framework
- Experimental program and set-up design
- Validation tests and experimental improvements
- First comparison of piles group behaviour
- Next experiments

Inclined piles in seismic area

Codes

- **PS92 :** "The use of inclined deep foundations is prohibited"
- **Eurocode 8 ch.5 :** "If inclined piles are used, they should be designed to safely carry axial loads as well as bending loads – note : it is recommended that no inclined piles be used for transmitting lateral loads "

Drawbacks (G. Gazetas technical report Quaker)

Bending moments induced by the soil settlement

Large alternating forces acting at the pile/pile cap interface

Large tensile forces which induced a decrease of the bending resistance of the inclined pile

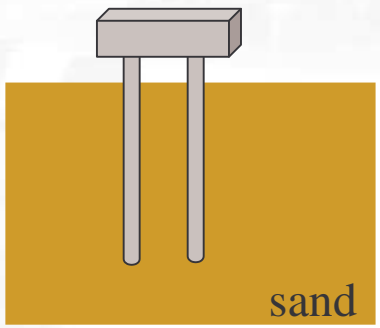
When inclination of the pile are not symmetric, permanent rotation may develop

Quaker program topic B1

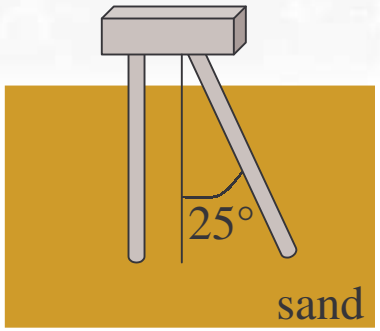
Behavior of deep foundations containing asymmetrically inclined pile under seismic loads

Development and **validation** of experimentally simplified methods

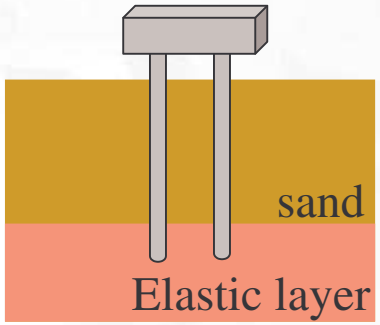
- two simplified piles groups : two piles connected with a rigid beam “fixed end conditions”
- two site conditions : floating and end bearing piles



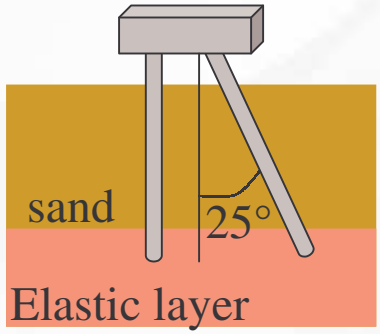
v-piles group
Floating piles



i-piles group
Floating piles



v-piles group
End bearing piles

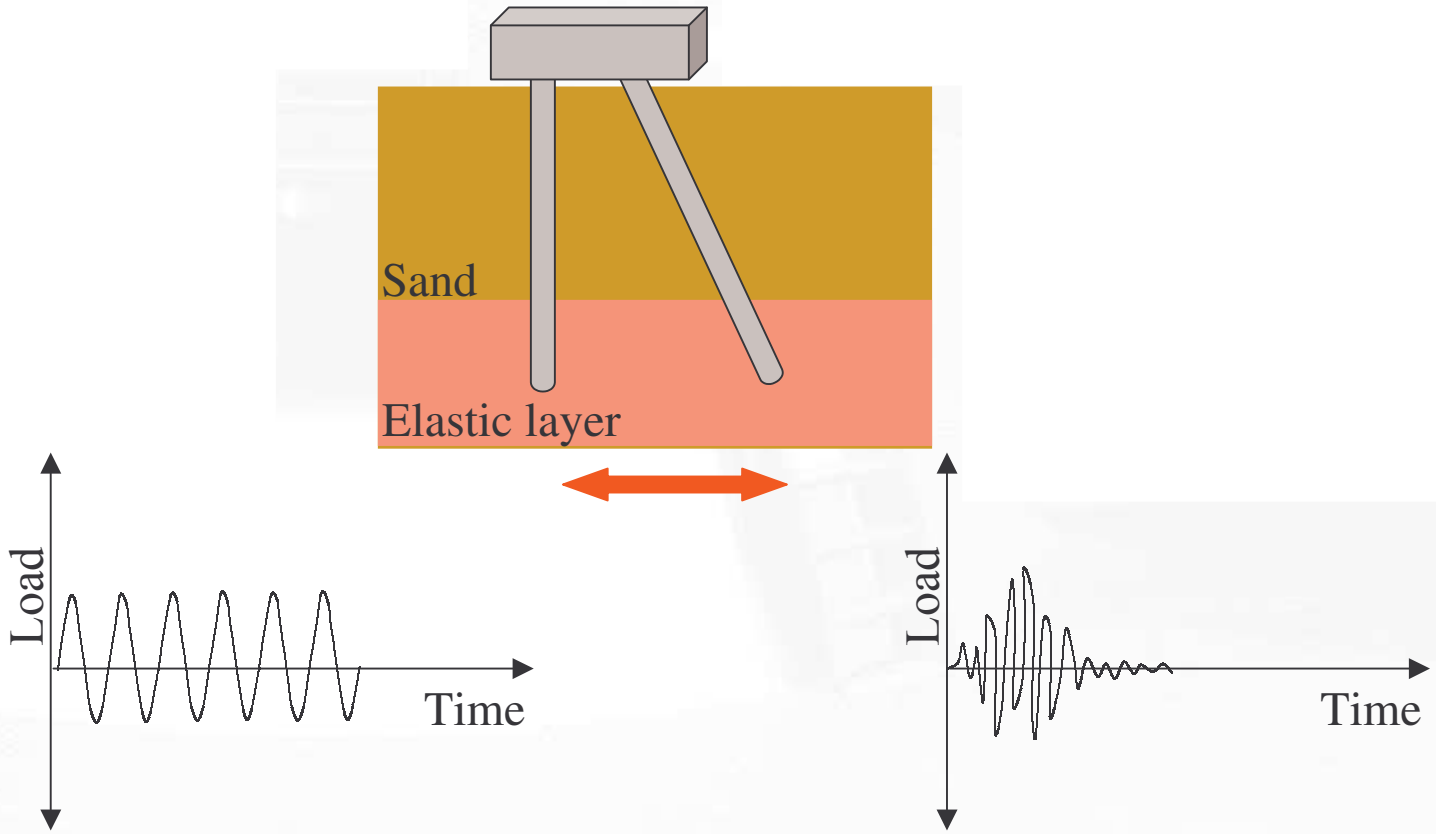


i-piles group
End bearing piles

Quaker program topic B1

➡ 4 types of loadings:

- No seismic loads
  - Horizontal static and cyclic loading
  - shock and repeated shocks
- Seismic loads
  - sine
  - earthquake



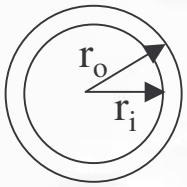
Set-up design

- **Soil and elastic layer**

- Fontainebleau sand : I_d=80% (γ_d≈16,09 kN.m^{-3}) ; ϕ ≈40°; E ≈ 23$p_c^{0.5}$ (Gaudin, 2002)

- Elastic layer : E≈480kPa

- **Piles design**

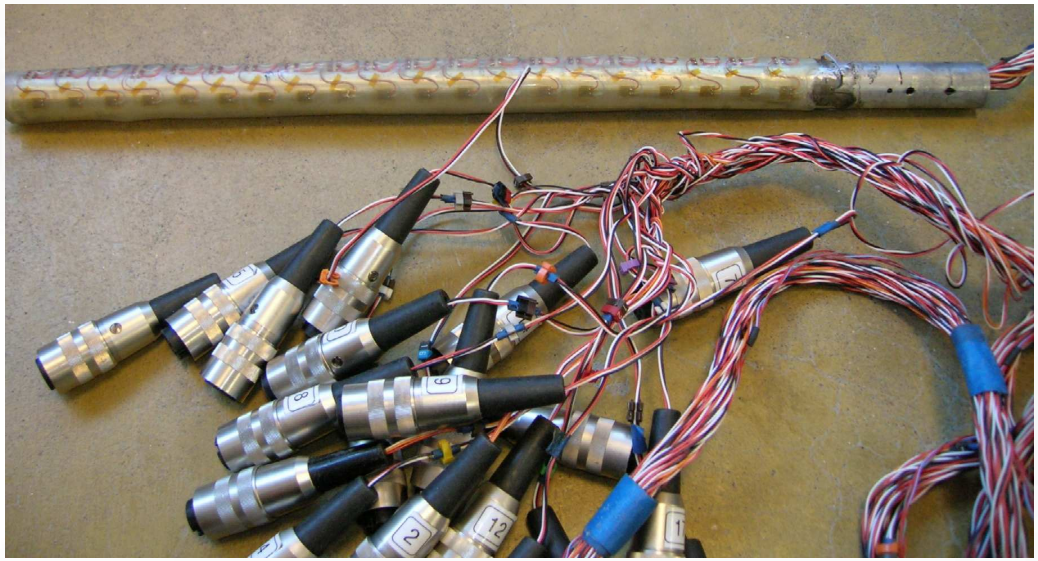


- Outer radius:36cm
- Inner radius:30cm
- EI: 197 MN.m²

- Penetration pile from ground: 12m

- Instrumented piles: 20 pairs of strain gages: bending moment profile

- No instrumented piles



Set-up design

Design and geometry of the piles group

Experimental program

First Series: **Devices and Installation Validation Elements Final Design**

Based on existing instrumented 12 m piles (strain gauges)

Friction piles

Static and cyclic horizontal loads

Shocks and repeated shocks

→ **Repeatability of the pile group response**

→ **Improvement of the experimental set-up**

Second Series: **Compared response to non seismic load**

4 new instrumented piles

Fast data acquisition system CAREMBA

Accelerometers in the sand

Friction and end bearing piles group

Static and cyclic horizontal loads

Shocks and repeated shocks

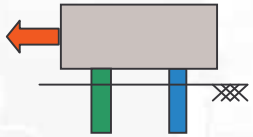
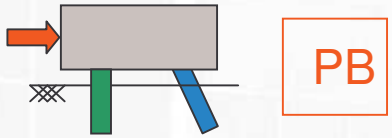
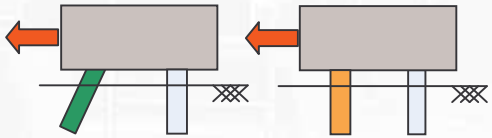
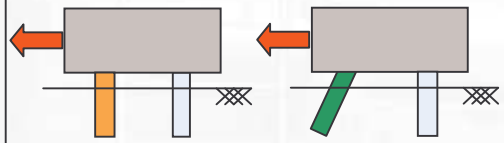
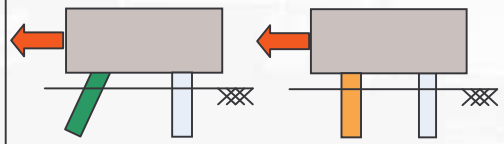
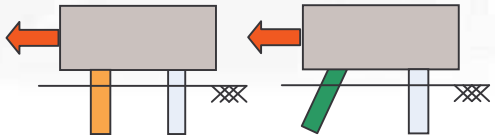
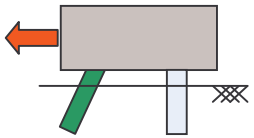
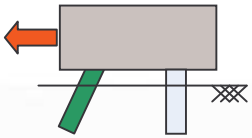
→ **Experimental data on the pile group behavior under non seimic loads**

Third Series: **Compared response to seismic load**

Shaker and laminar box

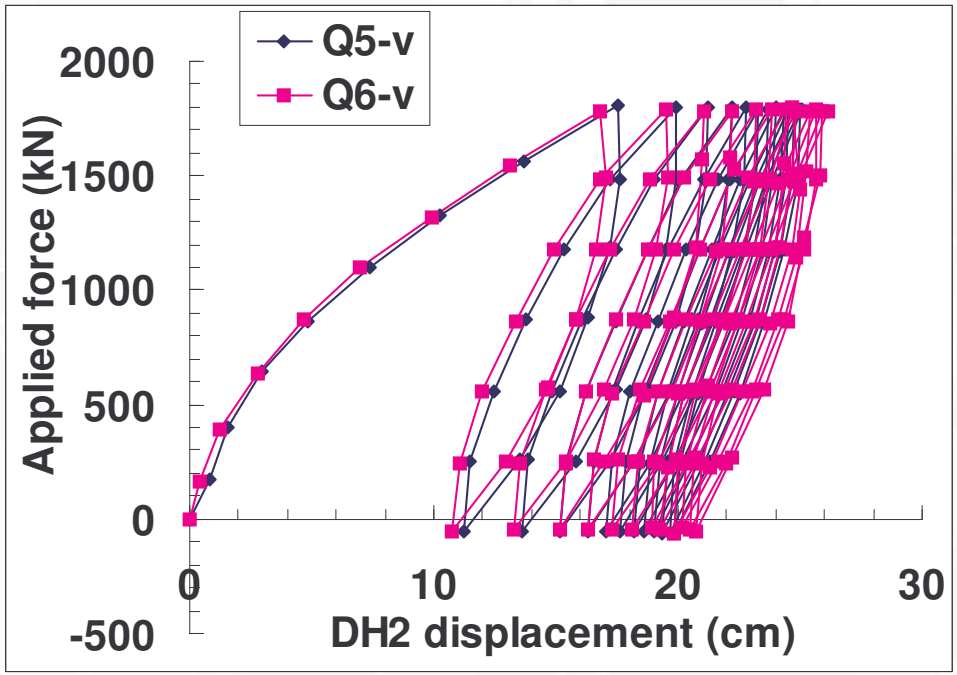
Sine (and earthquakes)

→ **Experimental data on the pile group behavior under seismic loads**

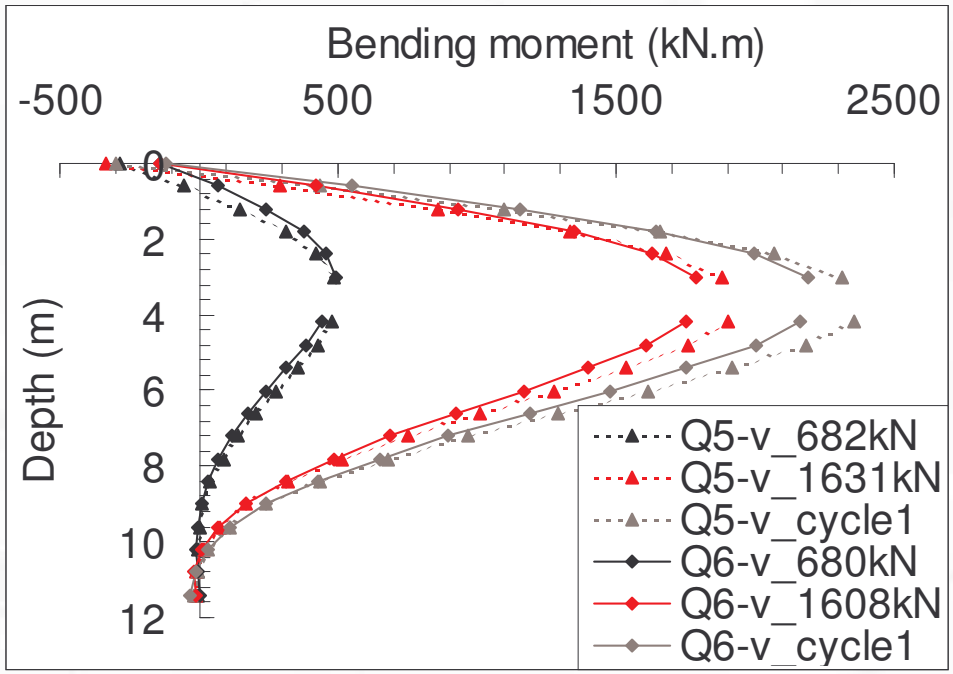
Box	Unit Weight ($g.cm^{-3}$)	Design	Loading	Improvements
Q1	16.06		Static+cyclic 0-960kN	
Q2	16.08		Static+cyclic 0-1920kN	
Q5	16.09		Static+ cyclic 0-1920kN	Pluviation_repositioning 2DS +1RS gages_axial force
Q6	16.11		Static+cyclic 0-1920kN	
Q7	16.1		Static+ cyclic 0-1920kN	Pluviation_thin cap +1RS
Q8	16.08		Static+cyclic 0-1920kN	
Q10	16.2		Static+ cyclic 0-1920kN	Pluviation_hanging in mid air
Q11	16.2		Static+cyclic 0-1920kN	

Friction piles - Group of two vertical piles

- **Head displacement**



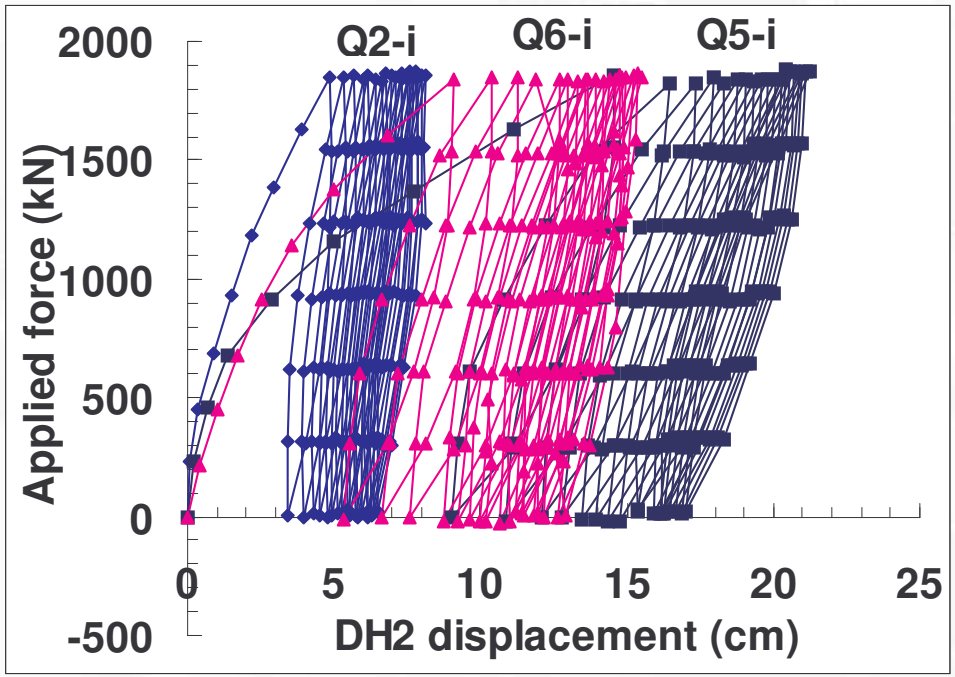
- **Bending moment profiles**



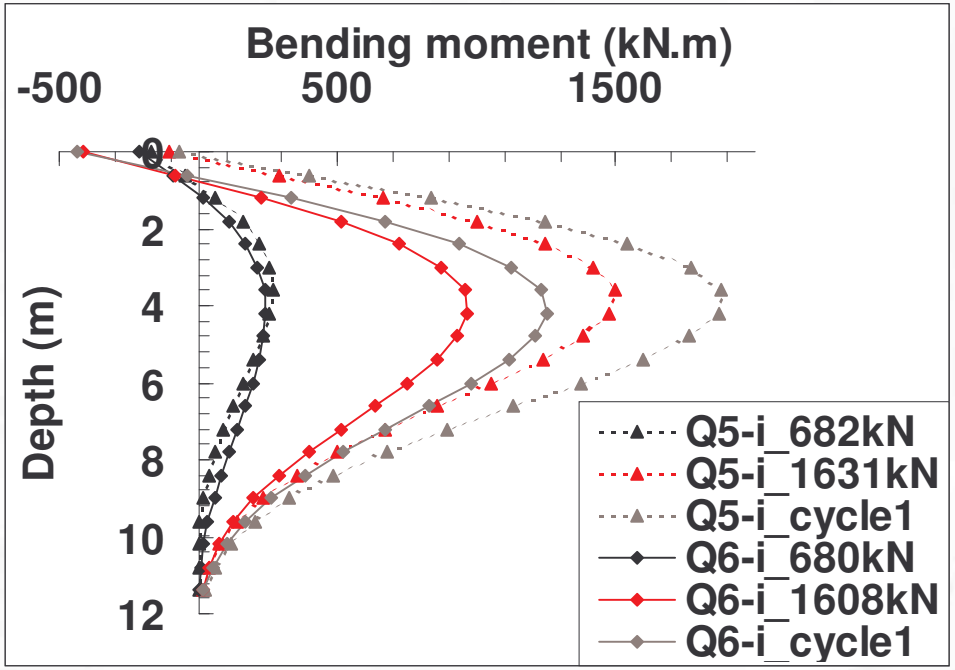
Test	DH2 displacement (cm)	
	Fmax	
	static	11 cycle
Q5-v	17.56	24.96
Q6-v	16.8	25.88
ΔQ/Qmin	**4.5%**	**3.7%**

Friction piles-Group of vertical and inclined piles

- DH2 displacement



- Bending moment profiles



Test	DH2 displacement (cm)		Maximum bending moment (KN/m)	
	Fmax		Fmax	
	static	11ème cycle	static	11ème cycle
Q5-i	14.56	20.28	1867	2337
Q6-i	9.08	14.4	1252	1786
ΔQ/Qmin	**52%**	**41%**	**49%**	**30%**

Improvements of the device and procedure

- **Improvement of the pile group placement in the box**

Rotation of the inclined pile

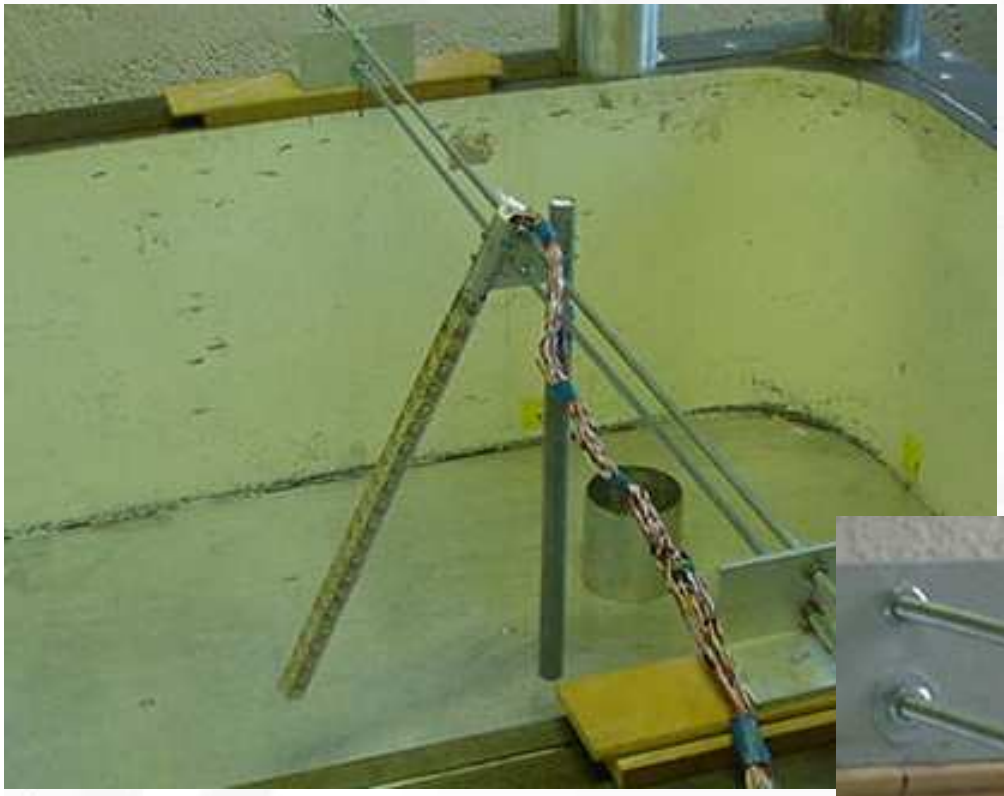
- Replacement of the pile → Modification of the soil structure
- No control of the distance bottom of the pile cap / sand surface

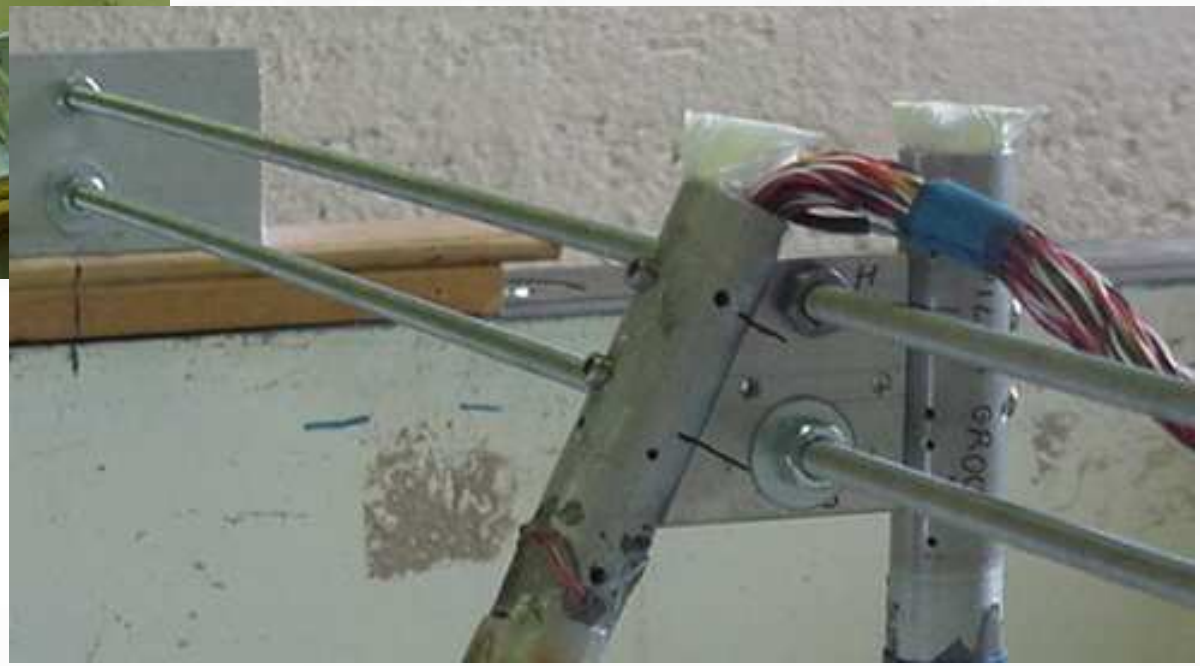
→ Thin pile cap + cable

no repeatability → Initially the pile group is push in the sand on 5 cm → Modification of the sand structure at the bottom of the pile

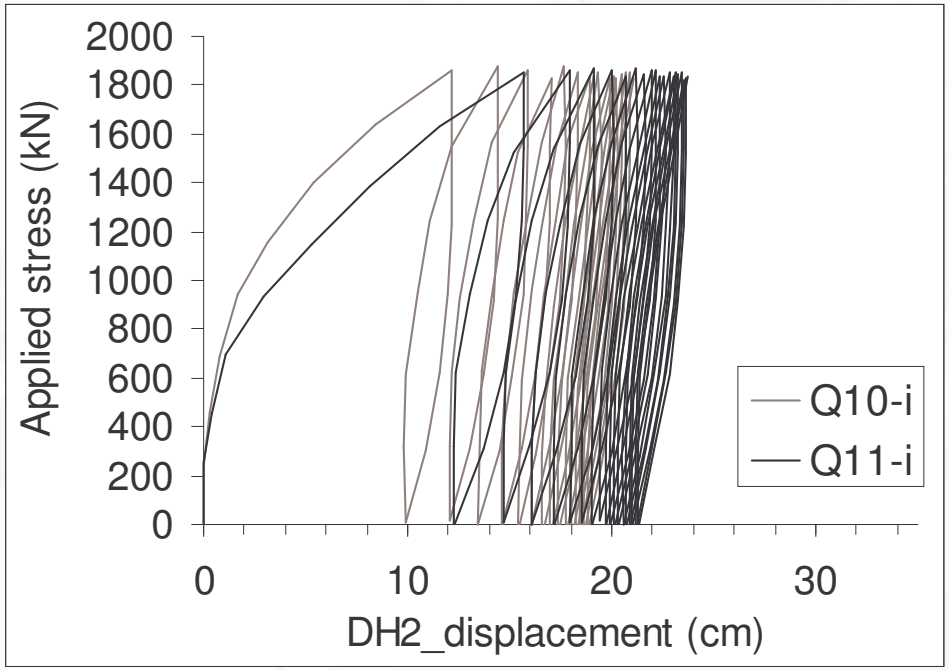
→ To suspend the piles group

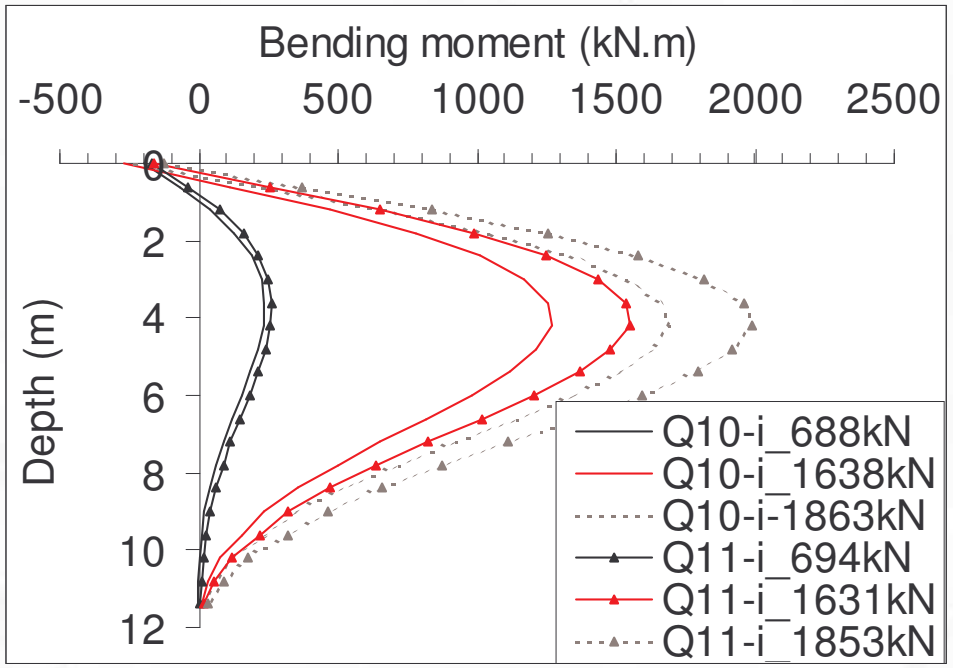
Friction piles-Group of vertical and inclined piles





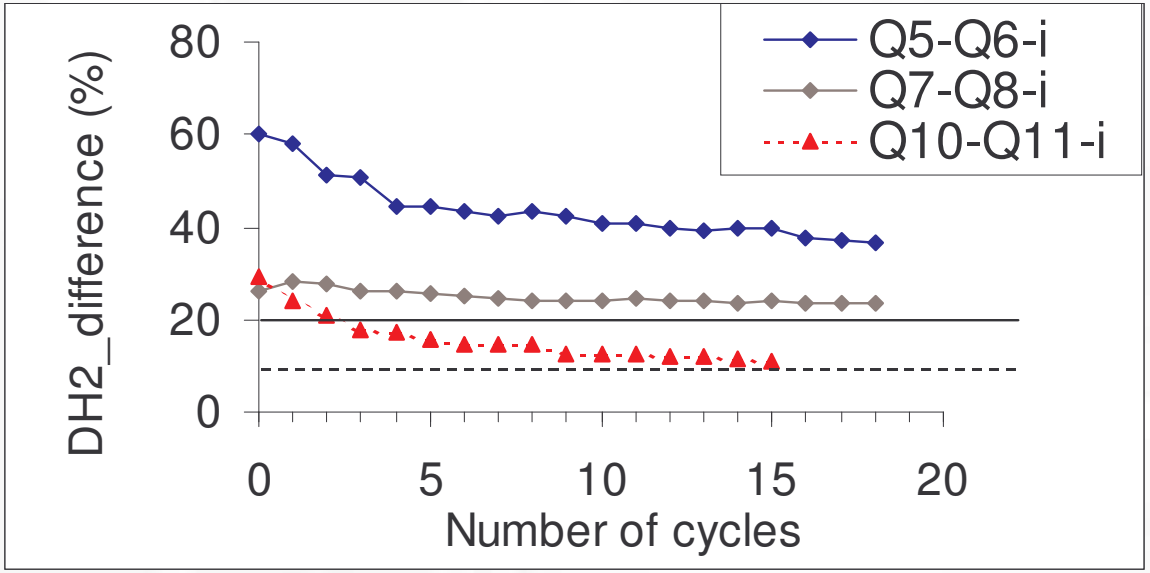
Friction piles-Group of vertical and inclined piles

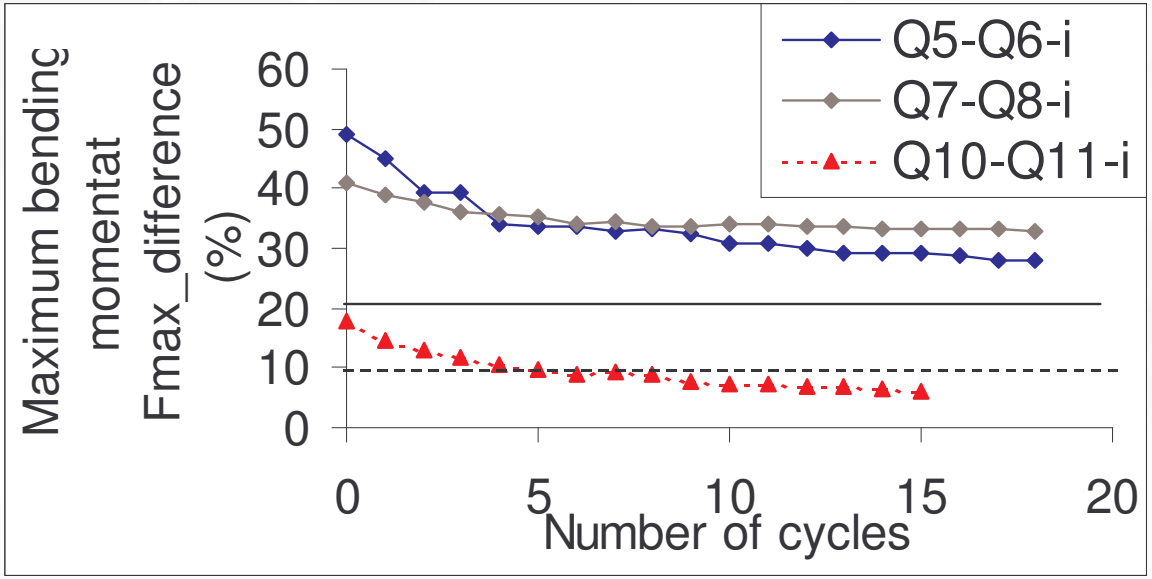




Test	DH2 displacement (cm)		Maximum bending moment (KN/m)	
	Fmax		Fmax	
	static	11ème cycle	static	11ème cycle
Q10-i	12.12	20.4	1689	2403
Q11-i	15.64	22.8	1990	2578
ΔQ/Qmin	**29%**	**11%**	**18%**	**7%**

Fixed-end moment piles group – first results





New experimental devices

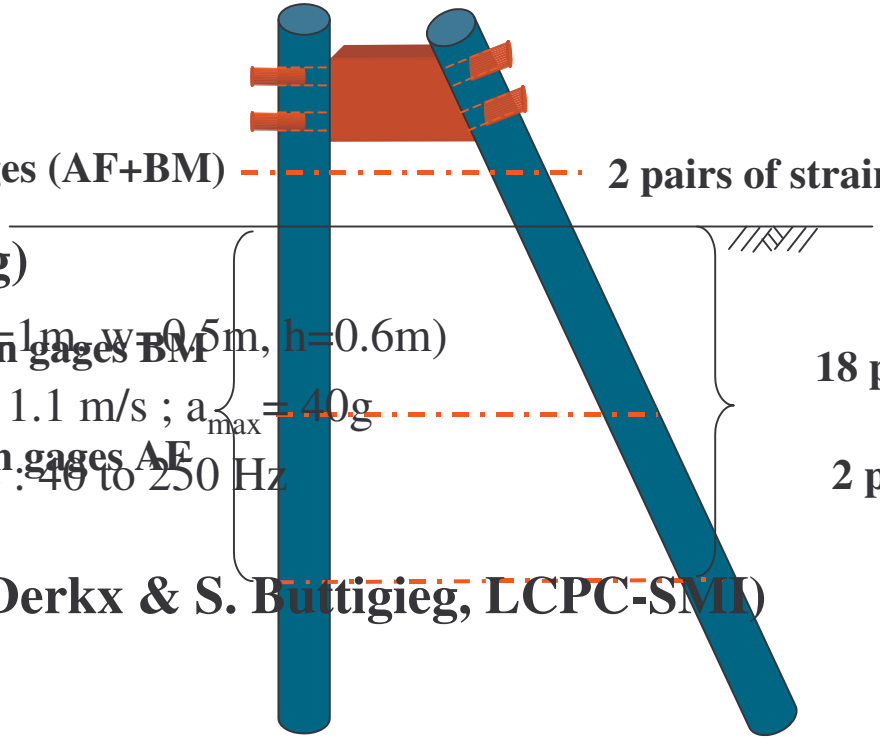
New piles

-Determination of the moment at the pile/pile cap interface: a pair of gages above the soil surface

→ The fixed-end moment can be determined

-Measurement of the normal force in the piles: feasability tests (no calibration)

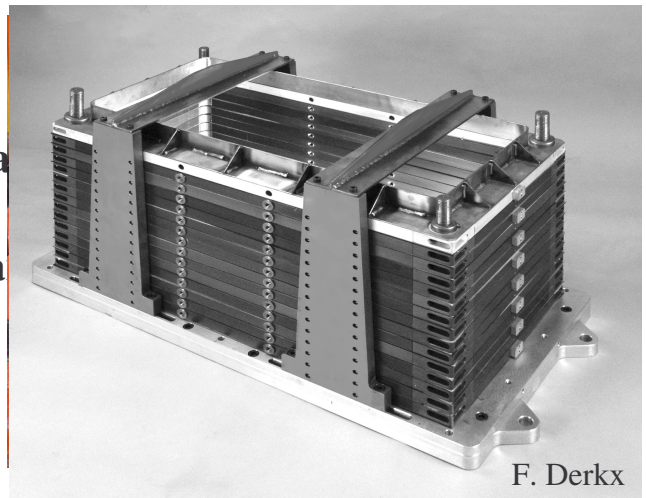
→ Additional pair of strain gages on the new pile



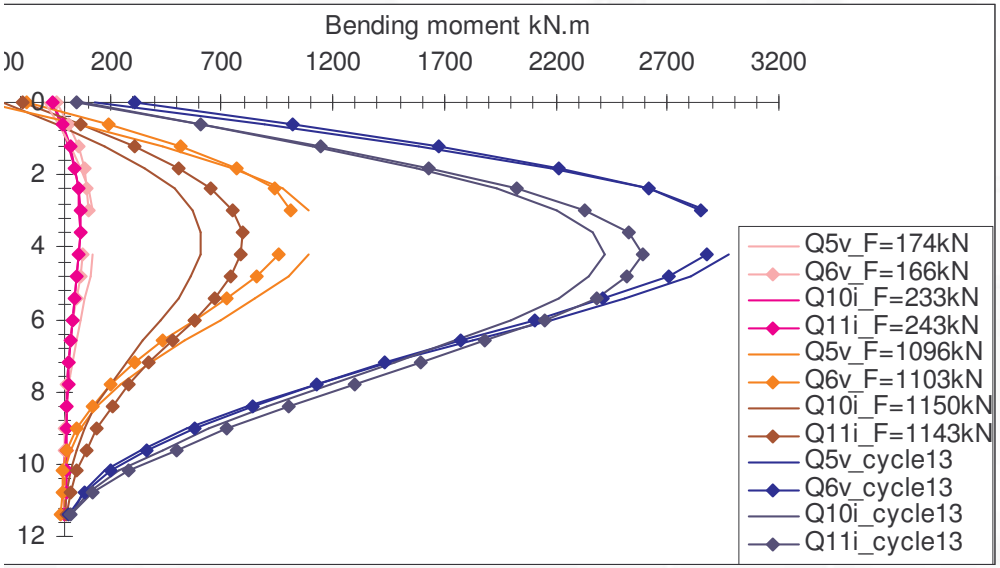
1D Shaker (10-80g)

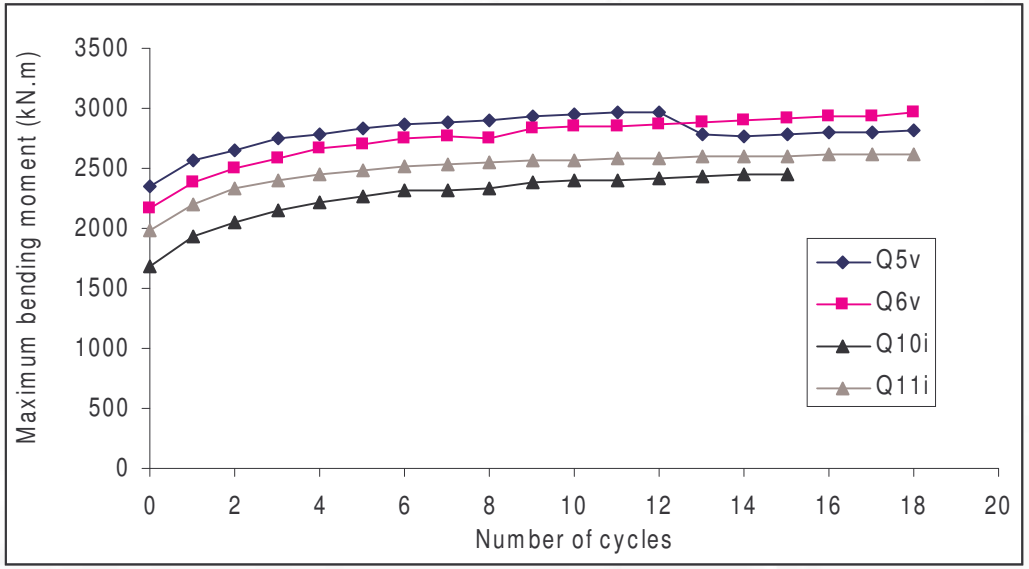
- Payload : 400kg (L=1m, w=0.5m, h=0.6m)
- U_{max} : 5mm ; V_{max} += 1.1 m/s ; a_{max} = 40g
- Frequency response : 40 to 250 Hz

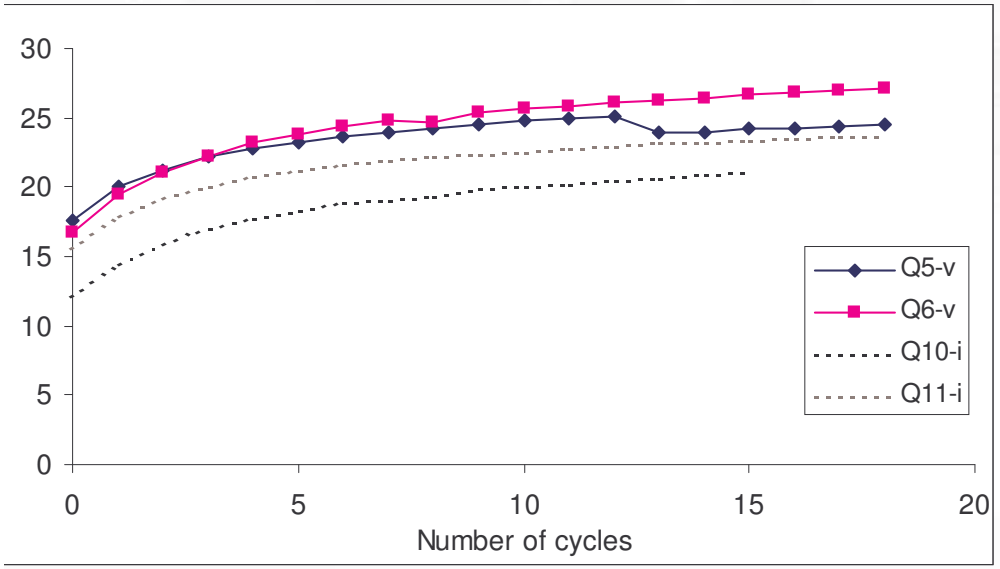
Laminar box (F. Derkx & S. Buttigieg, LCPC-SMI)


F. Derkx

First comparison of piles group behaviour



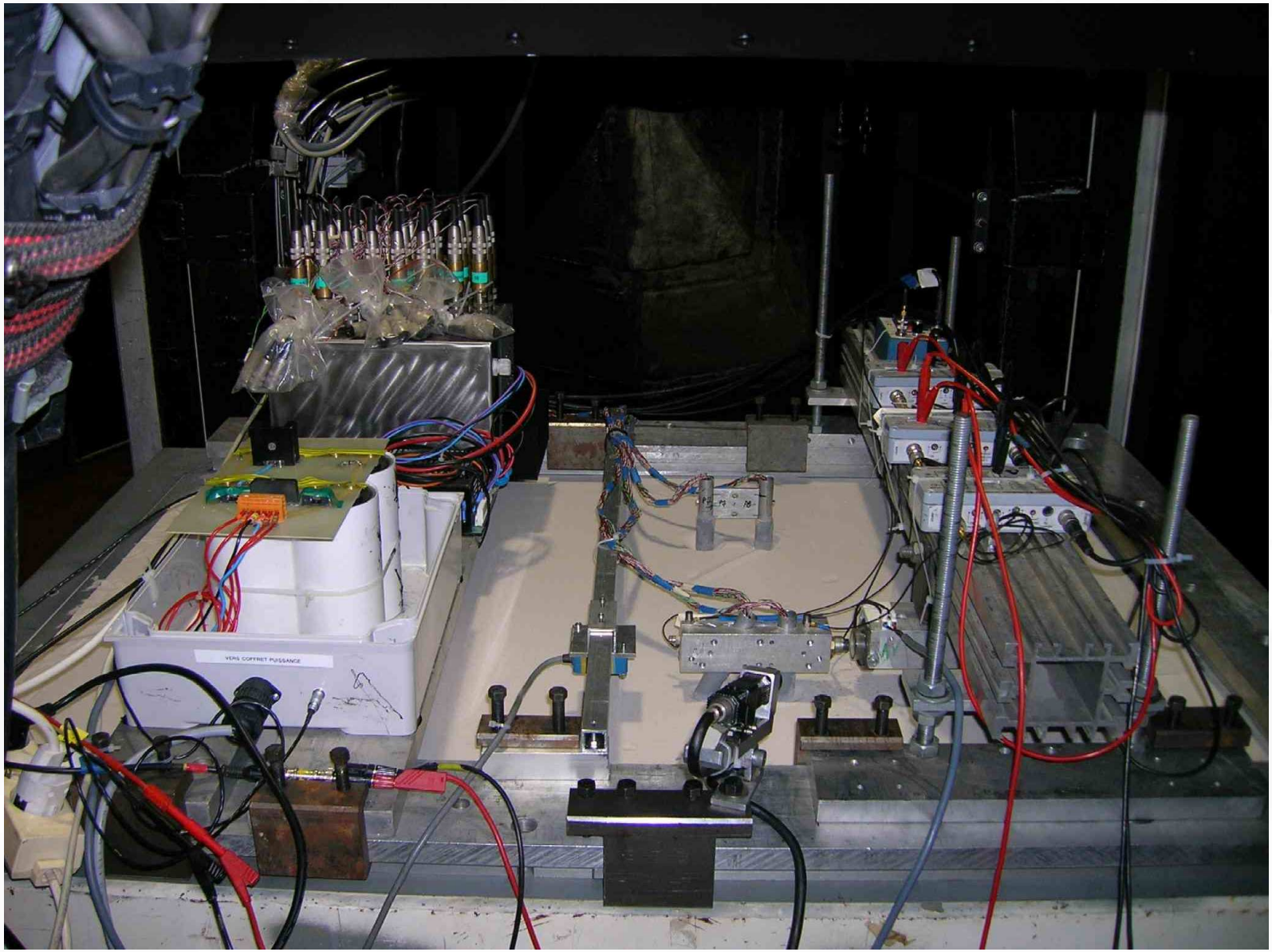




- Bending moments are higher for the vertical pile group
- Horizontal displacements are higher for the vertical pile group

More information are necessary to understand the stress distribution (axial force in the piles)

Next experiments



Next experiments

First Series: **Devices and Installation Validation Elements Final Design**

Based on existing instrumented 12 m piles (strain gauges)

Friction piles

Static and cyclic horizontal loads

Shocks and repeated shocks

→ **Repeatability of the pile group response**

→ **Improvement of the experimental set-up**

Second Series: **Compared response to non seismic load**

- 4 new instrumented piles
- Fast data acquisition system CAREMBA
- Accelerometers in the sand

Friction and end bearing piles group

Static and cyclic horizontal loads

Shocks and repeated shocks

→ **Experimental data on the pile group behavior under non seimic loads**

Third Series: **Compared response to seismic load**

Shaker and laminar box

Sine (and earthquakes)

→ **Experimental data on the pile group behavior under seismic loads**