Long-Term Performance Assessment of Micropiles Subject to Cyclic Axial Loading

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ISM 2007 Toronto, Canada
September 27, 2007

Summary

1. Problem Definition & Research Needs
2. Model: Creep & Cyclic Displacement
3. Model Validation
   - * Structural Laboratory (New York)
   - Calibration Chamber (Paris)
4. Conclusions

Industry Applications

Bridges & Highways

Railways

Land-based Arresting Gear
(Courtesy of U.S. Navy)

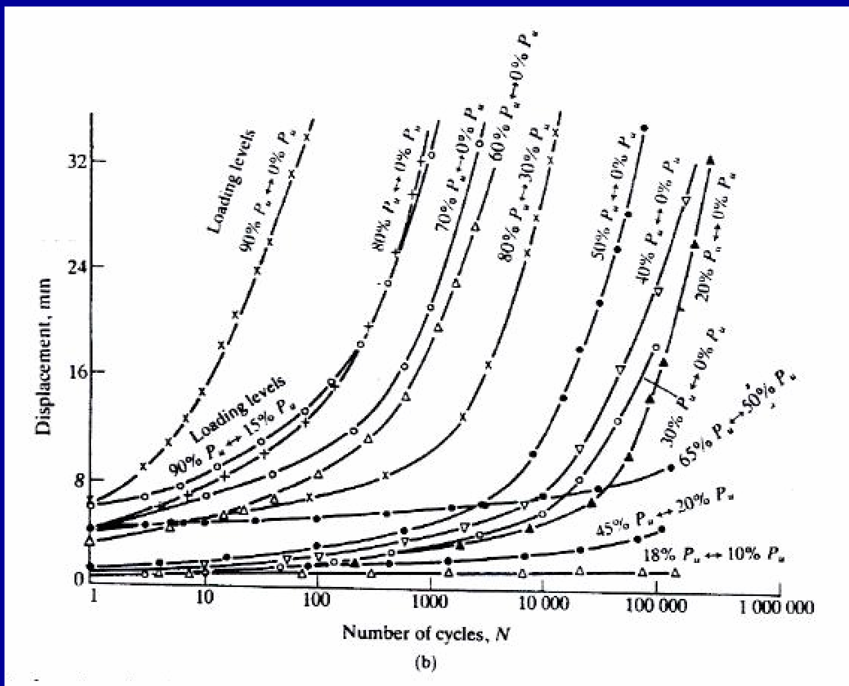
Waterfront/Harbors

Power

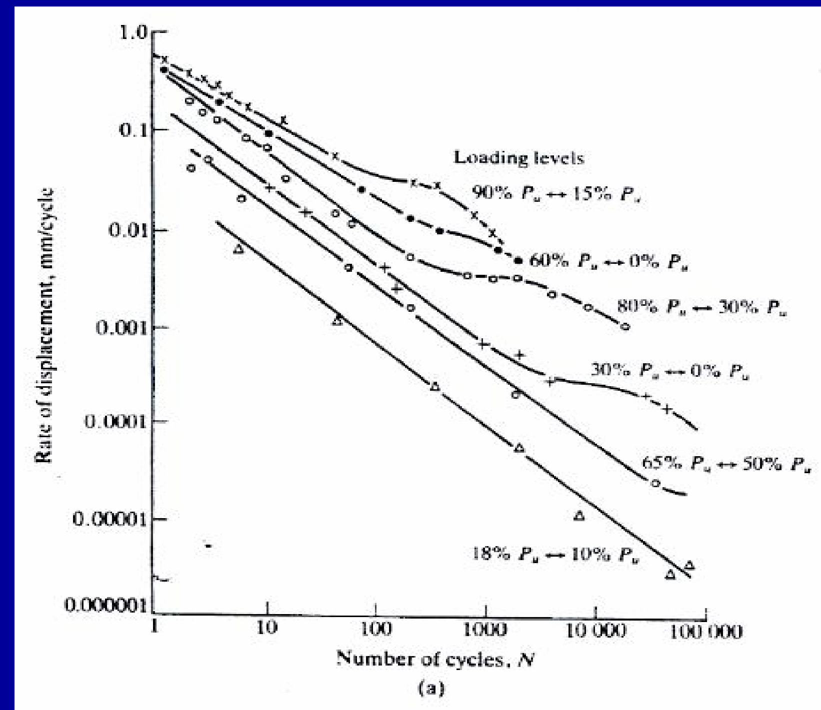
Cyclic Strain

A time-dependent phenomena

$q\ ,\delta\ ,\ n$

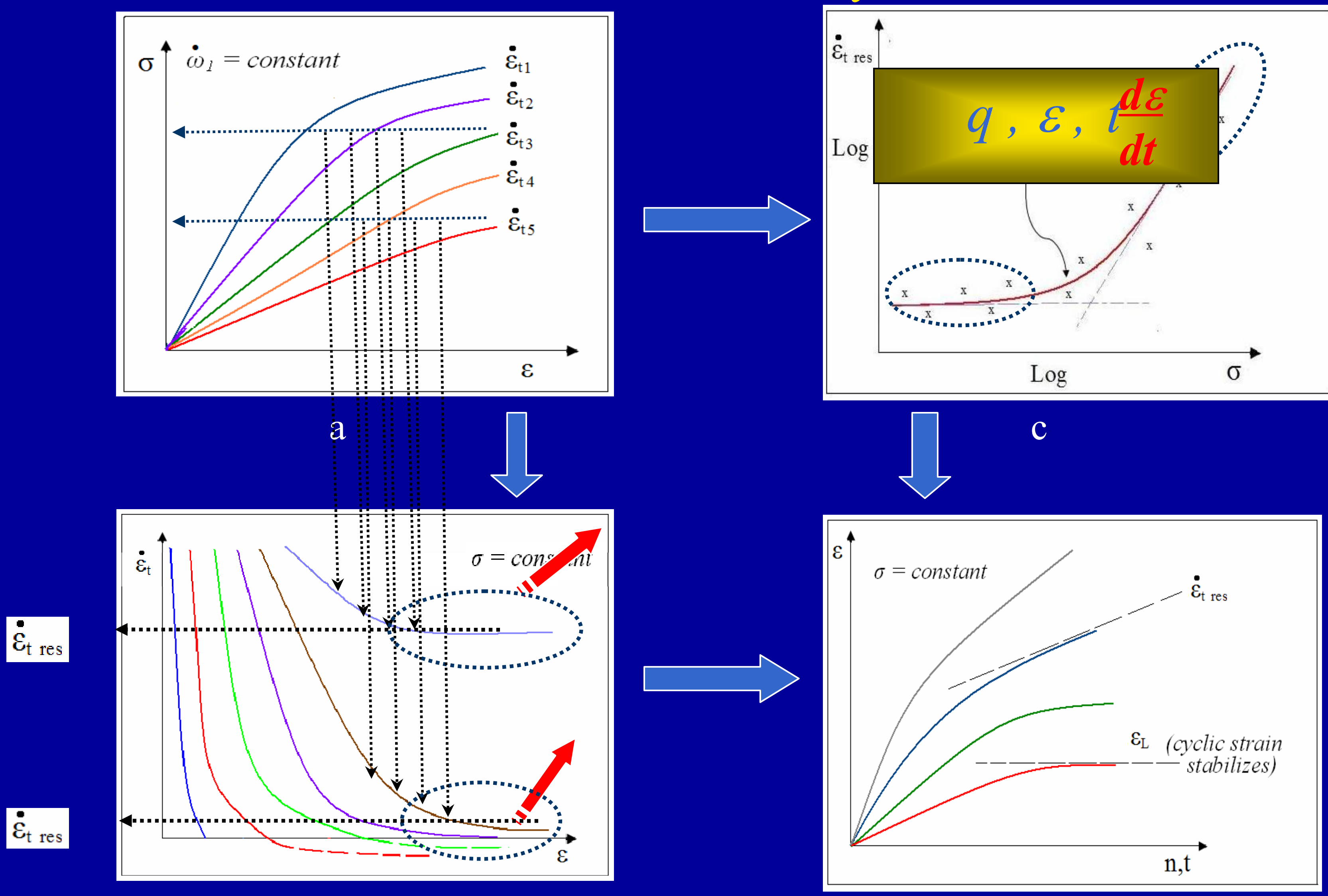


The effect of number of load cycles on anchor displacement for a range of load amplitudes (After Al-Mosawe, 1979)



The effect of load cycles on the rate of anchor displacement (After Al-Mosawe, 1979)

Strain Rate Model for Cyclic Strain



b

$$\frac{d\varepsilon}{dt} = \dot{\varepsilon} = \dot{\varepsilon}_o * \varepsilon^{-\beta} + \dot{\varepsilon}_{res}$$

d

$$\varepsilon(t) = [\varepsilon_o (\beta + 1)]^{1/(\beta+1)} \ x \ t^{1/(\beta+1)}$$

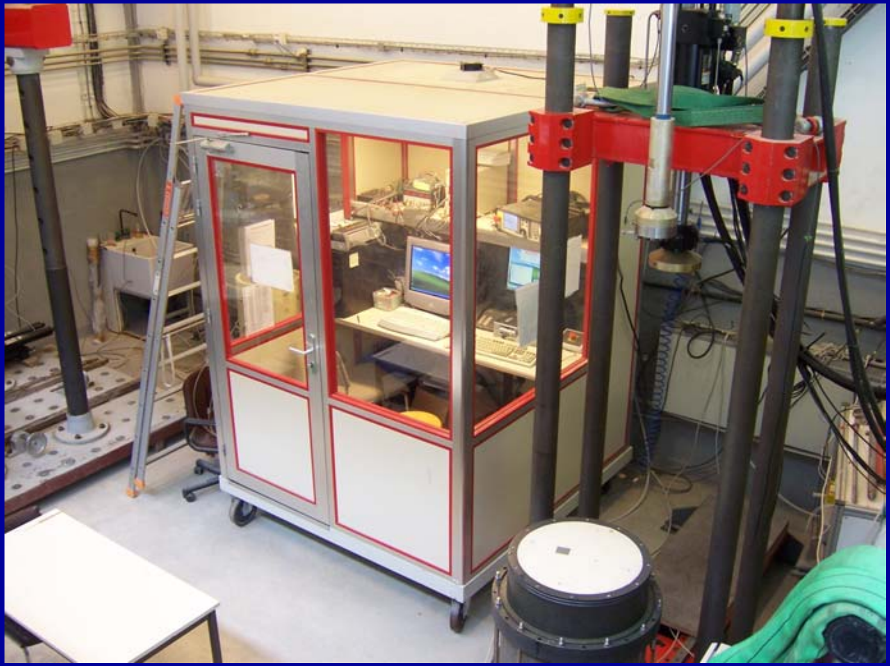
The procedure charts including (a) stress, σ, vs. strain, ε, at constant strain rate (b) strain rate vs. strain, ε at constant stress (c) residual strain rate vs. stress, σ and (d) strain, ε, vs. cycle number, n at constant stress

Ecole Nationale des Ponts et Chaussées

CERMES

Centre d’Enseignement et de Recherche en Mécanique des Sols

CERMES
Calibration Chamber



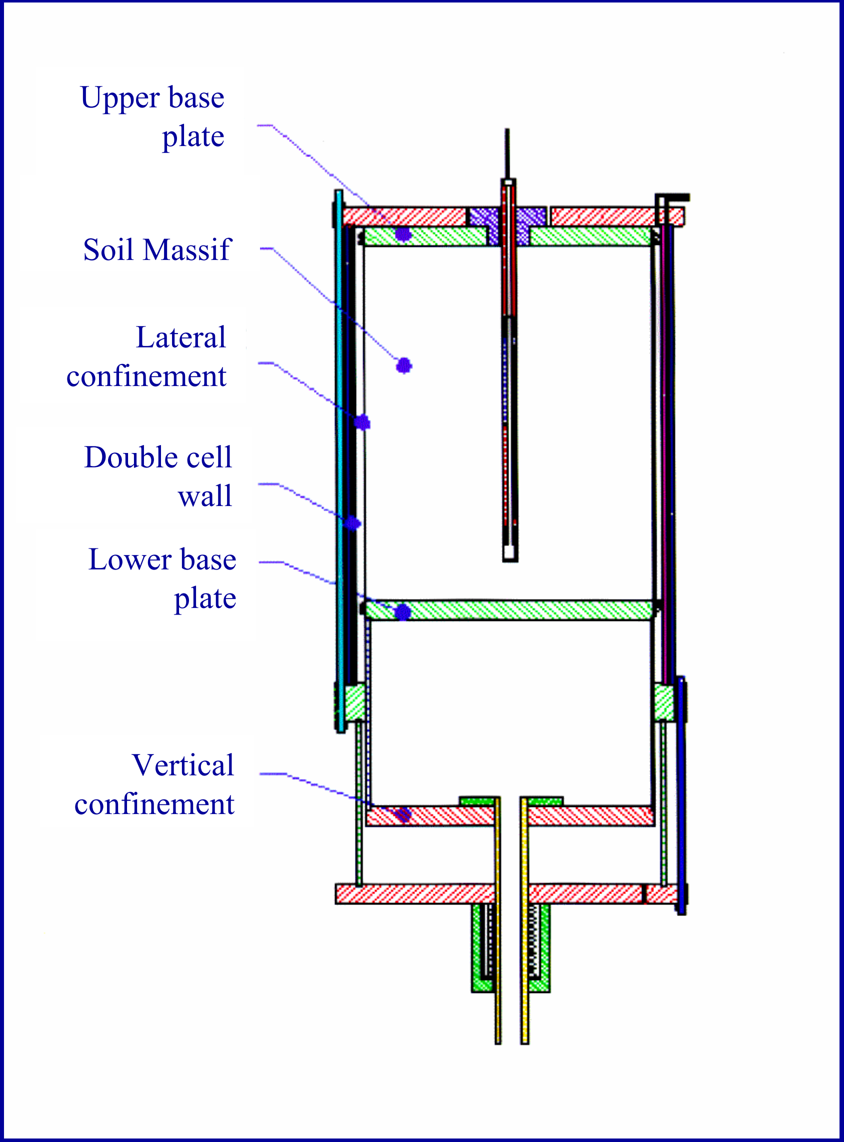
FORVEVER

FOREVER (1992-2002)

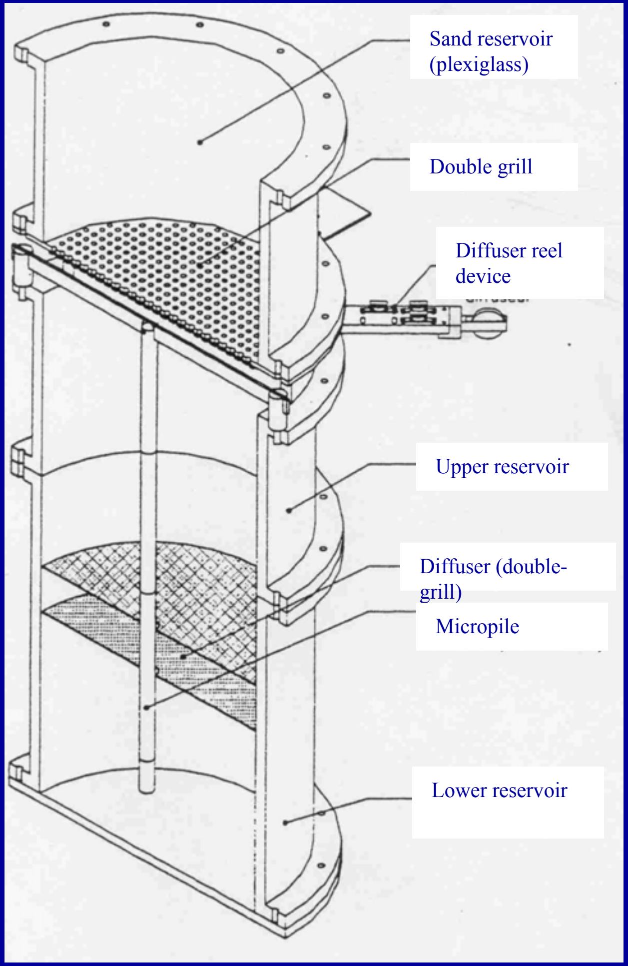
- Physical modeling of micropiles and micropile systems
- Controlled testing conditions (stress level, density, etc.)
- Monotonic & cyclic loading

Calibration Chamber

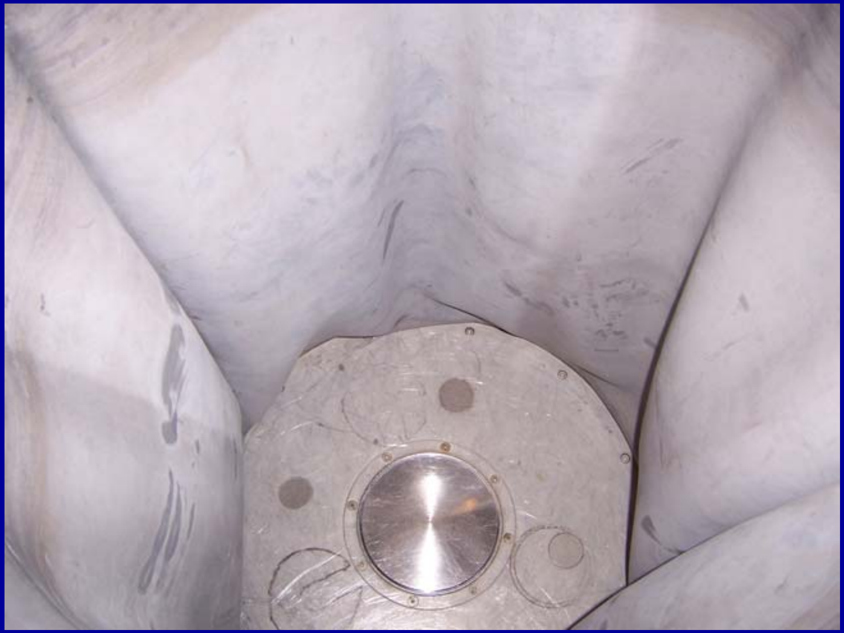
1. *Preparation of massif*
2. *Implementation of test protocol*
3. *Initialize data acquisition system*
4. *Jacking of instrumented pile*
5. *Loading of micropile*
6. *Demounting massif*

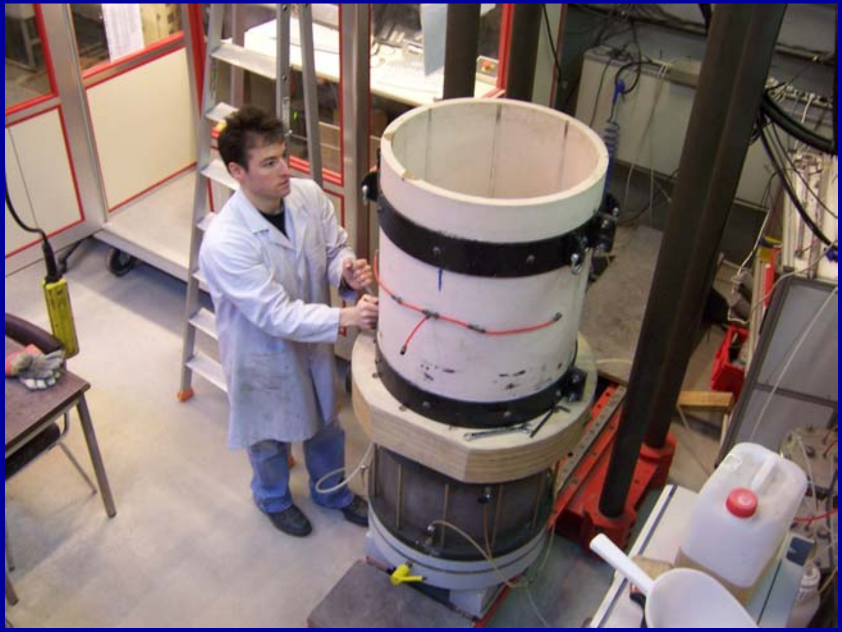


Calibration Chamber - Schematic



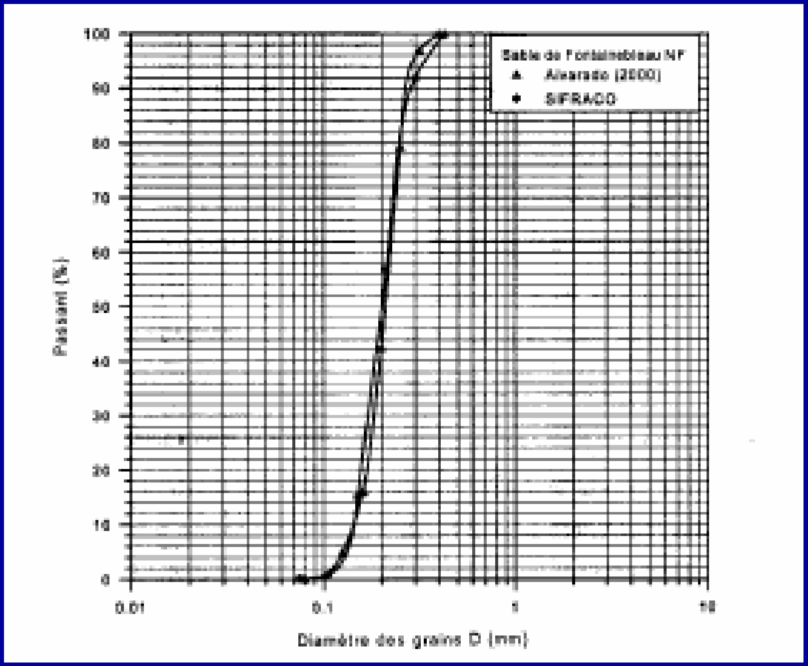
System of Pluviation





Preassembly of Chamber

Fontainebleau Soil



Gradation Properties

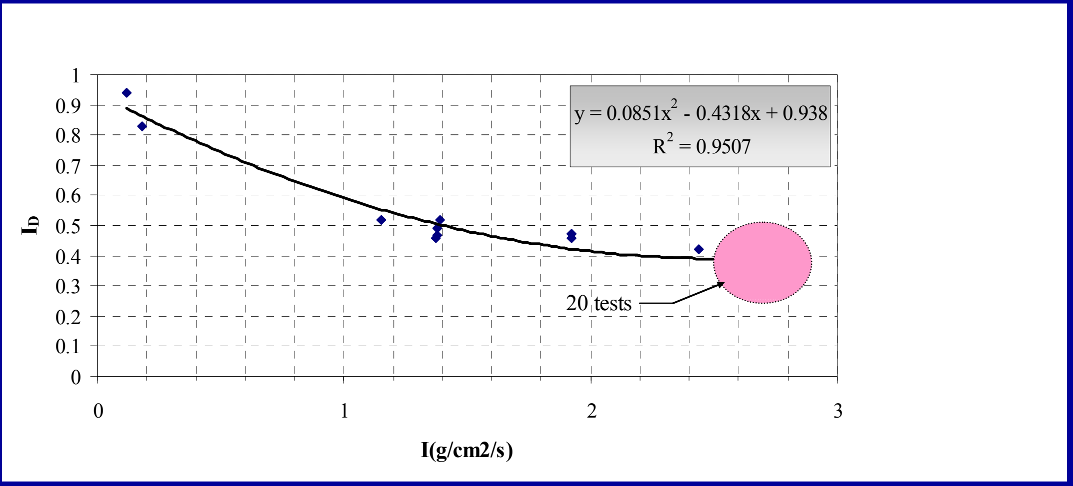
St Rémy-lès-Chevreuse

Sand	D_{50} (mm)	e_{max}	e_{min}	ρ_s(g/cm^3)	ρ_d(g/cm^3)	ρ_{dmax} (g/cm^3)
AF	0.21	0.94	0.54	2.65	1.37	1.72

Massif

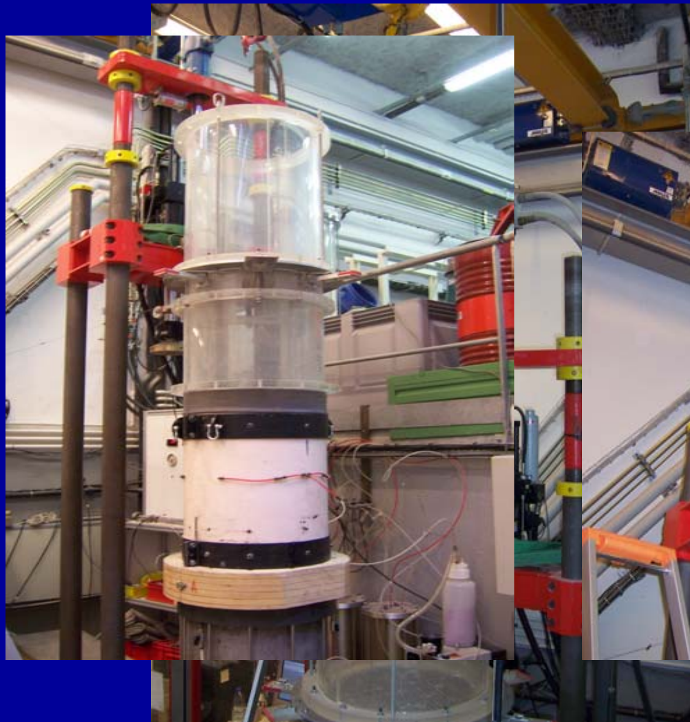
Test No.	Designation	M_s (Kg)	I(g/cm^2/s)	I_D
1	MDRC-0			
2	MDRC-1	225.38	2.72	0.405
3	MDRC-1b	224.96	2.71	0.396
4	MDRC-1c	224.06	2.70	0.378
5	MDRC-3	221.92	2.67	0.335
6	MDRC-3a	222.96	2.69	0.356
7	MDRC-3b	224.38	2.70	0.385
8	CDRC-1	223.96	2.70	0.376
9	CDRC-2	224.56	2.70	0.388
10	CDRC-3	224.24	2.70	0.382
11	FDRC-1	223.94	2.70	0.376
12	FDRC-2	225.54	2.72	0.408
13	FDRC-2a	223.96	2.70	0.376
14	FDRC-3	224.22	2.70	0.382
15	FDRC-4	224.64	2.71	0.390
16	FDRC-4a	225.28	2.71	0.403
17	FDRC-5	225.82	2.72	0.414
18	FDRC-6	225.72	2.72	0.412
19	FDRC-8	225.83	2.72	0.414
20	FLC-1	225.52	2.72	0.408
21	FLC-2	225	2.71	0.397

Massif Calibration



Density Index vs. Deposition Intensity

Pluviation

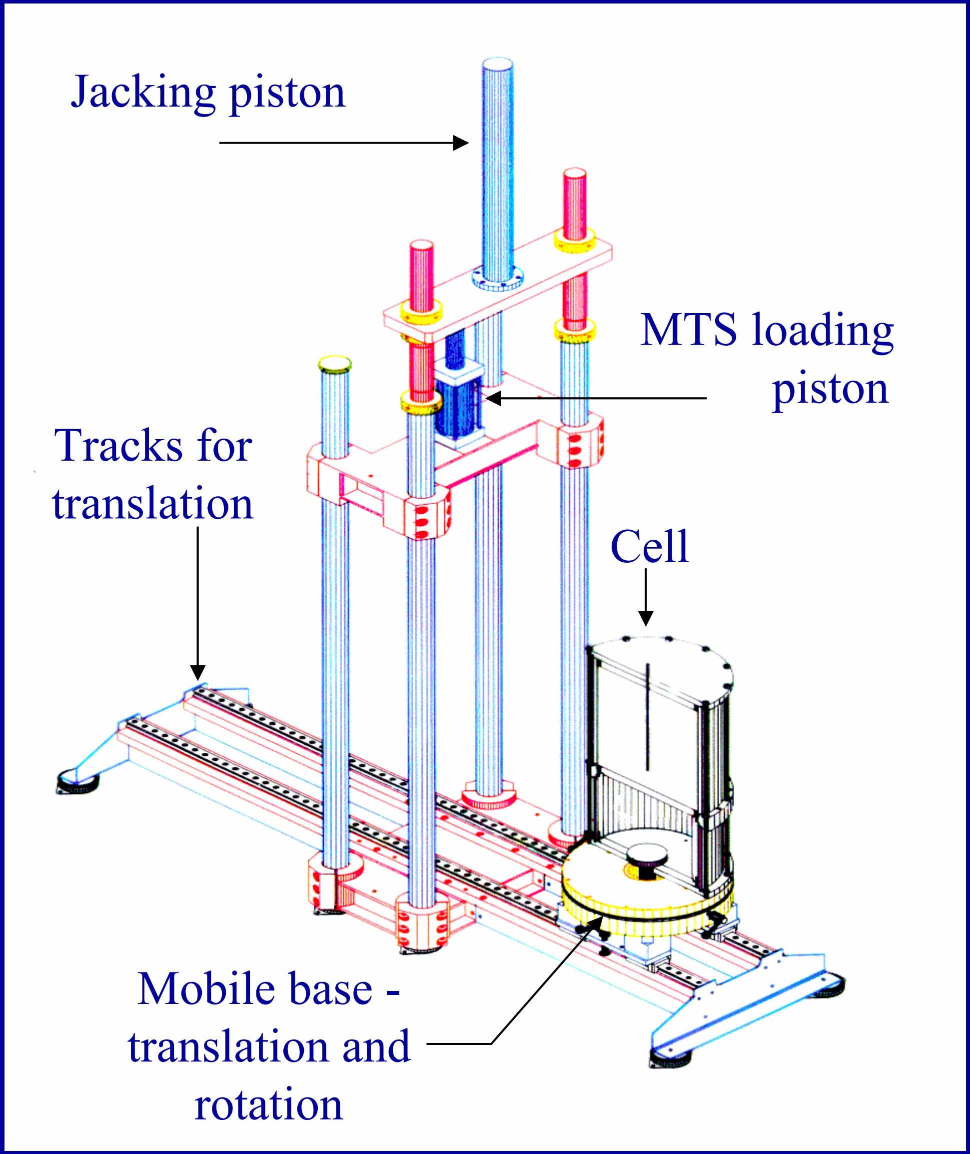




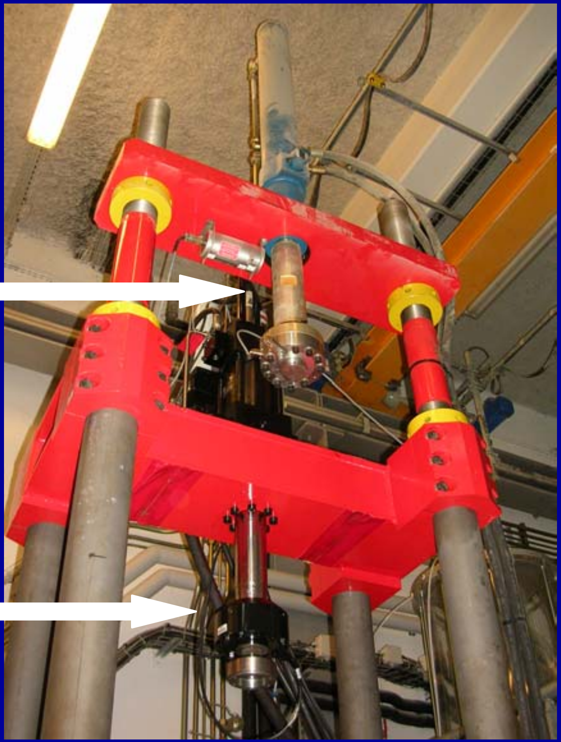

Application of Vacuum/Counterpressure

Application of Stresses

Principle Schematic

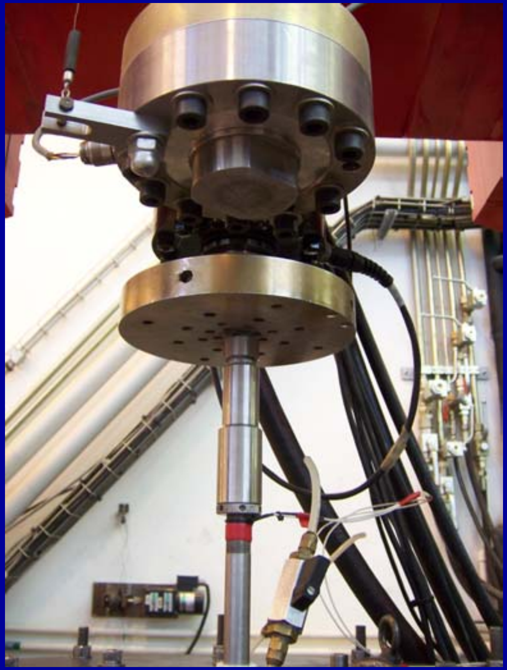


Jacking & Loading



Hydraulic jack
Single stroke
(force transducer)

Loading jack
(Displacement & force transducer at head)

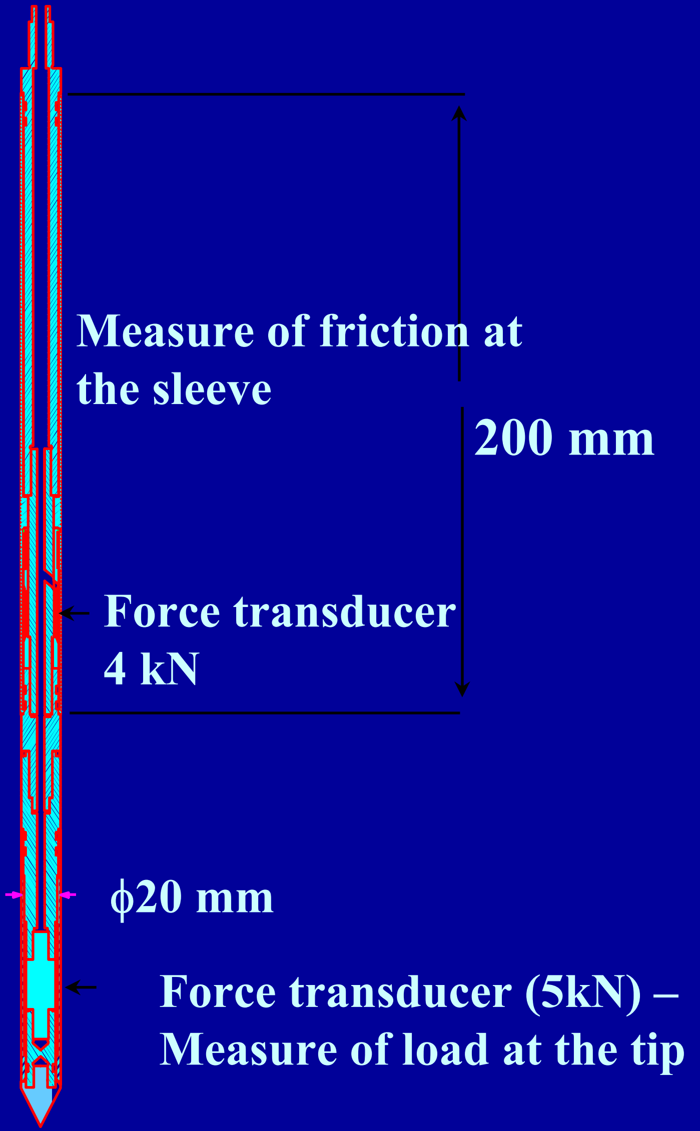


Loading of micropile

Jacking of micropile

Instrumented Micropile

[Instrumented micropile](#)



Test Schedule

Test Number	Designation	Applied Displacement Rate (mm/min)	Cyclic Displacement Rate (mm/cycle)	Frequency Rate (cycle/min)	Q_{Peak} (kN)	$q_{p\ Peak}$ (MPa)	$f_{s\ Peak}$ (kPa)	δ_{max} (mm)	δ_e (mm)	δ_p (mm)	$q_{p,res}$ (MPa)	$f_{s,res}$ (kPa)
1	MDRC-0	1	na	na	5.06	6.85	68.37	5.13	4.64	4.64	0.88	-0.44
2	MDRC-1	1	na	na	4.38	6.26	60.96	59.80	59.80	59.80	1.13	-1.86
3	MDRC-1b	1	na	na	4.34	6.58	43.06	24.92	24.92	24.92	0.90	-2.48
4	MDRC-1c	1	na	na	4.59	6.31	62.52	24.90	24.90	24.90	0.89	-1.76
5	MDRC-3	0.2	na	na	4.14	5.22	54.22	24.91	24.91	24.91	0.75	-0.48
6	MDRC-3a	0.2	na	na	5.01	5.98	73.07	19.93	19.93	19.93	0.69	-1.54
7	MDRC-3b	0.2	na	na	4.38	5.45	66.03	19.92	19.92	19.92	1.03	-0.63
8	CDRC-1	1	0.2	5	4.84	4.84	75.91	3.58	3.23	3.23	0.57	0.61
9	CDRC-2	0.25	0.05	5	4.61	4.01	86.43	2.49	2.23	2.23	0.56	1.18
10	CDRC-3	0.02	0.004	5	3.40	3.13		0.96	0.78	0.78	0.59	
11	FDRC-1	1	1	1	4.69	5.82	67.10	10.98	10.63	10.63		
12	FDRC-2	1	0.1	10	4.21	4.50	57.57	9.99	9.72	9.72	0.13	0.18
13	FDRC-2a	1	0.1	10					1.10	1.10		
14	FDRC-3	1	0.02	50	3.56	3.89	56.47	10.86	10.66	10.66		
15	FDRC-4	1	0.004	250	2.55	2.88	54.95	1.07	0.94	0.94	0.83	0.83
16	FDRC-4a	1	0.004	250					1.20	1.20		
17	FDRC-5	1	0.002	500	2.29	2.92	55.34	1.02	0.83	0.83	0.79	0.79
18	FDRC-6	1	0.001	1000	2.04	2.79	51.74	1.00	1.00	1.00	0.22	0.22
19	FDRC-8	1	0.0004	2500	1.87	2.64	47.63	0.53	0.45	0.45		
20	FLC-1	1	na	na	3.17	4.21	45.07	17.47	17.29	17.29		
21	FLC-2	1	na	na	1.82	3.05	52.22	0.77	0.67	0.67		

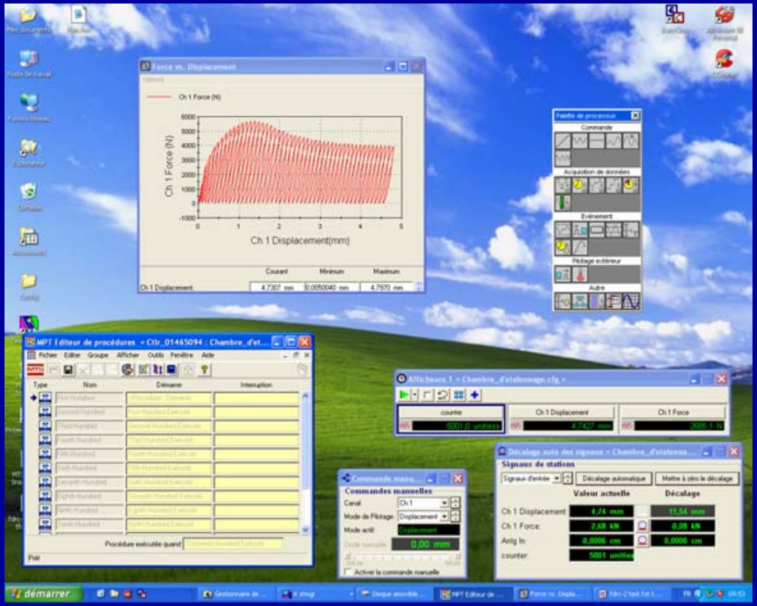
Testing Summary

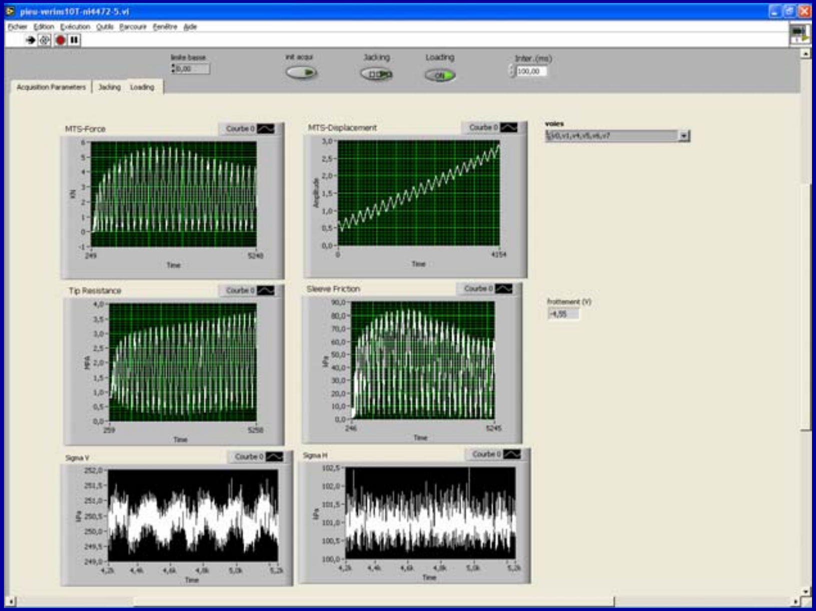
1. Monotonic displacement rate control – Effect of rate
2. Cyclic displacement rate control – Effect of frequency
3. Cyclic load control – Validation of testing methodology & model

Establishment of Critical Cyclic Load

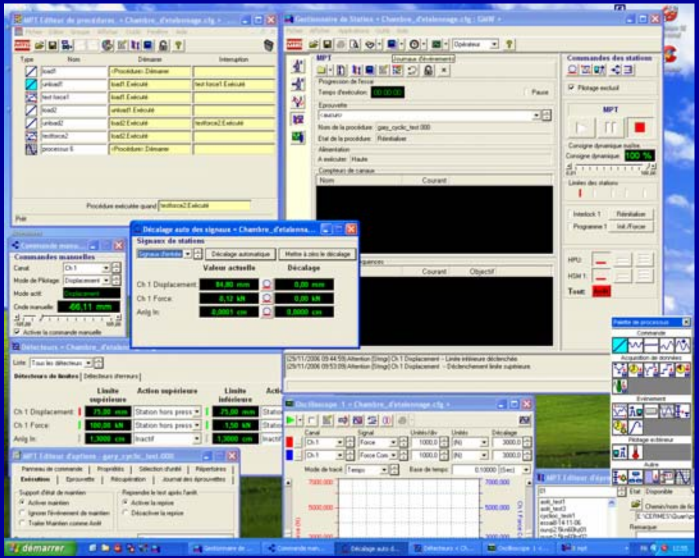
Test Control & Data Acquisition

Mission Control



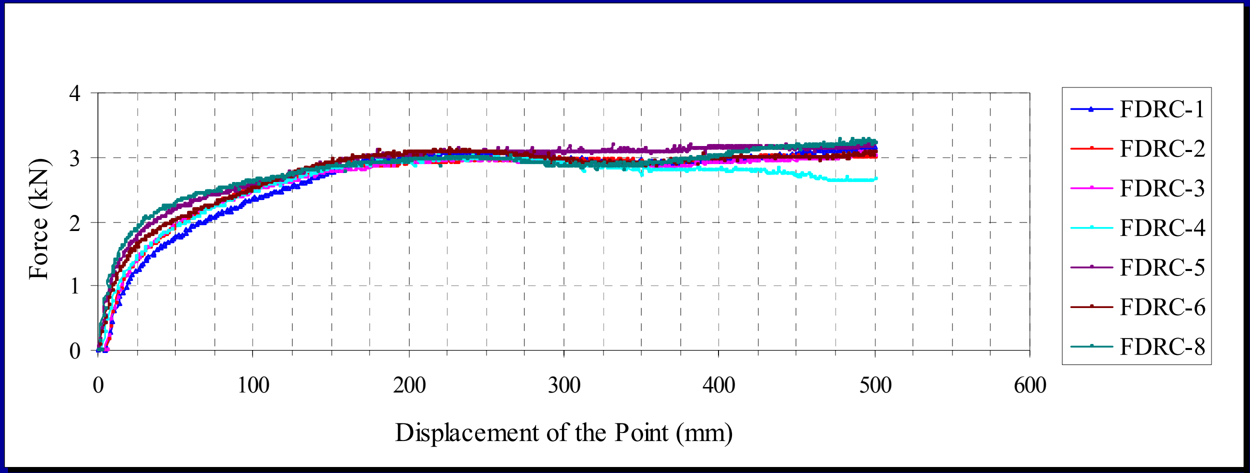


LABView Environment

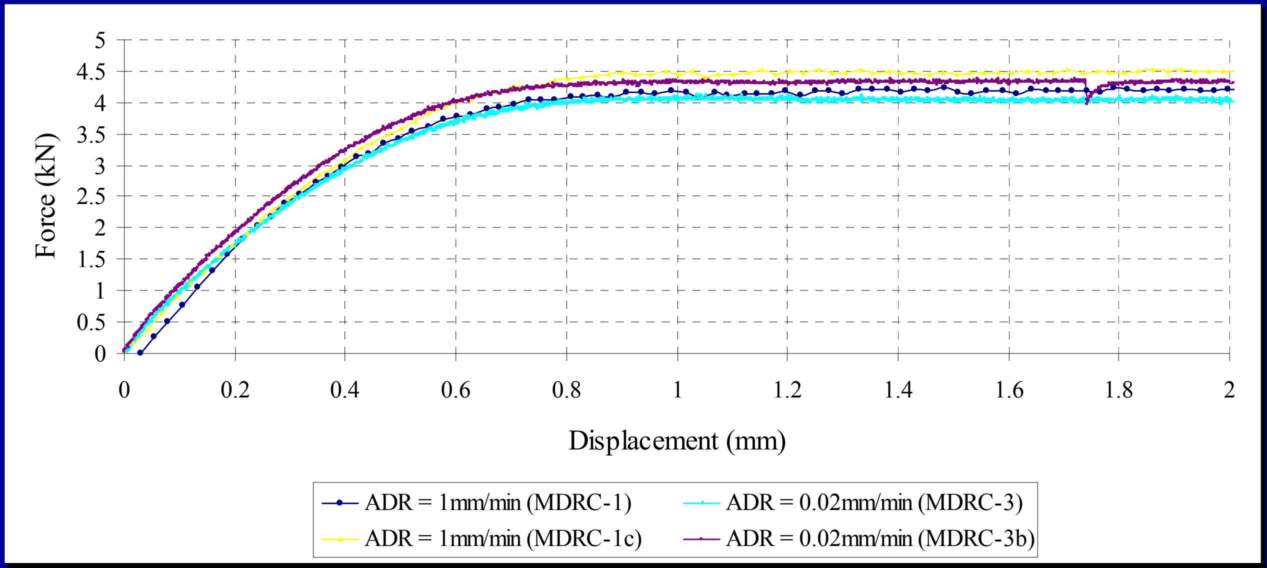


MTS FlexTest System

Repeatibility & Rate Effects

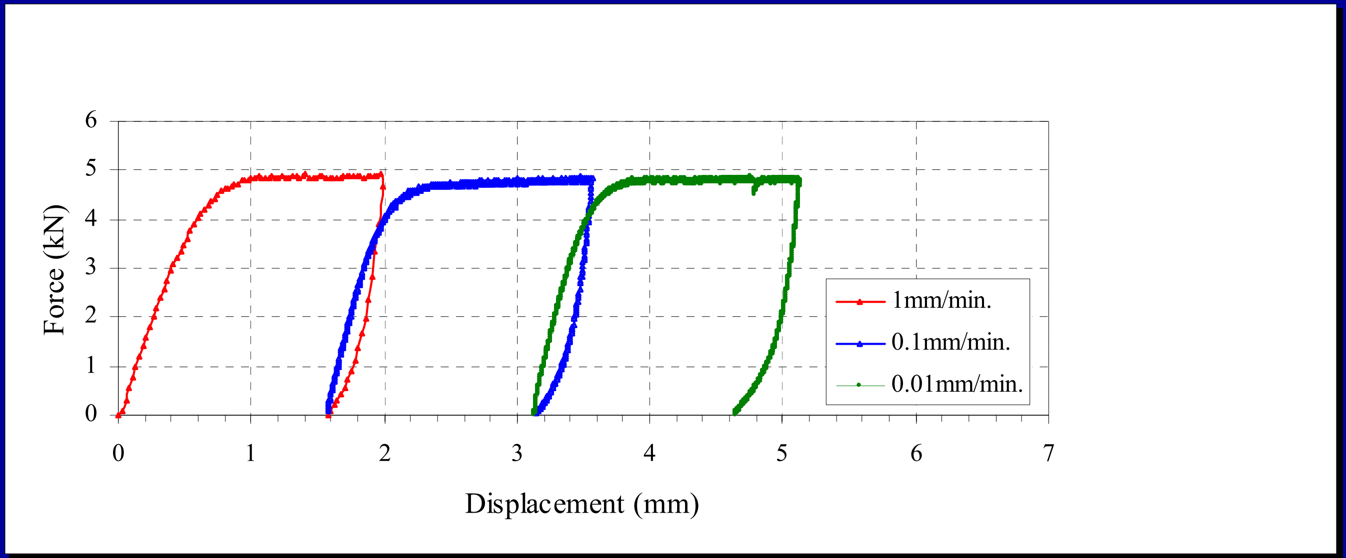


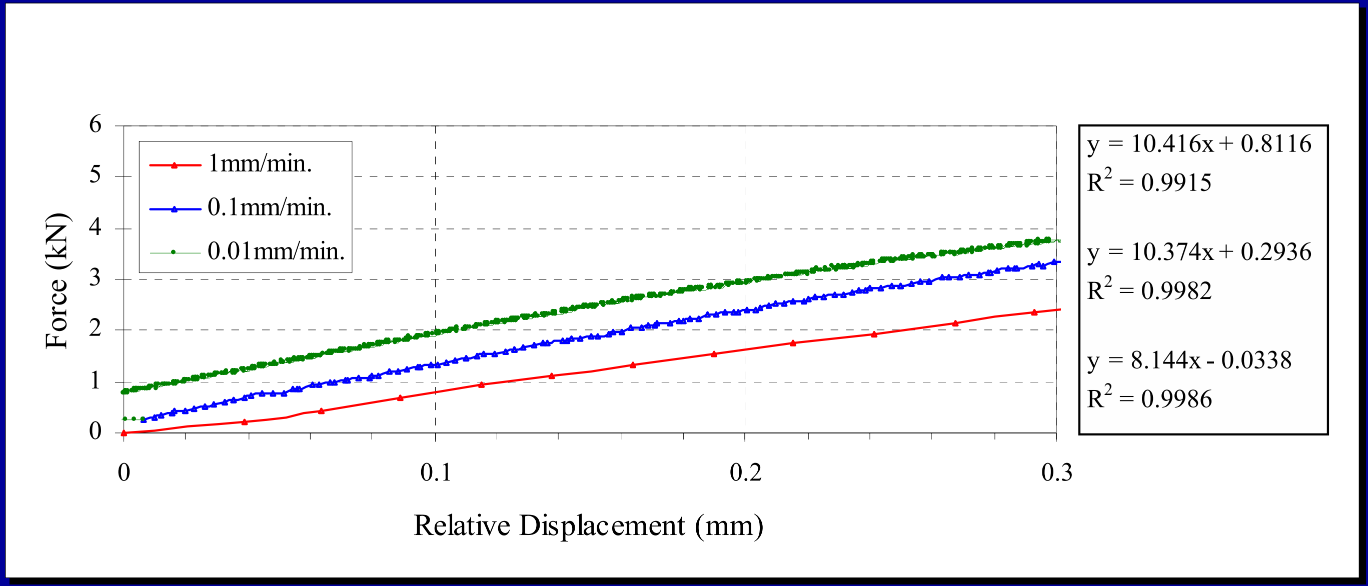
Jacking



Loading

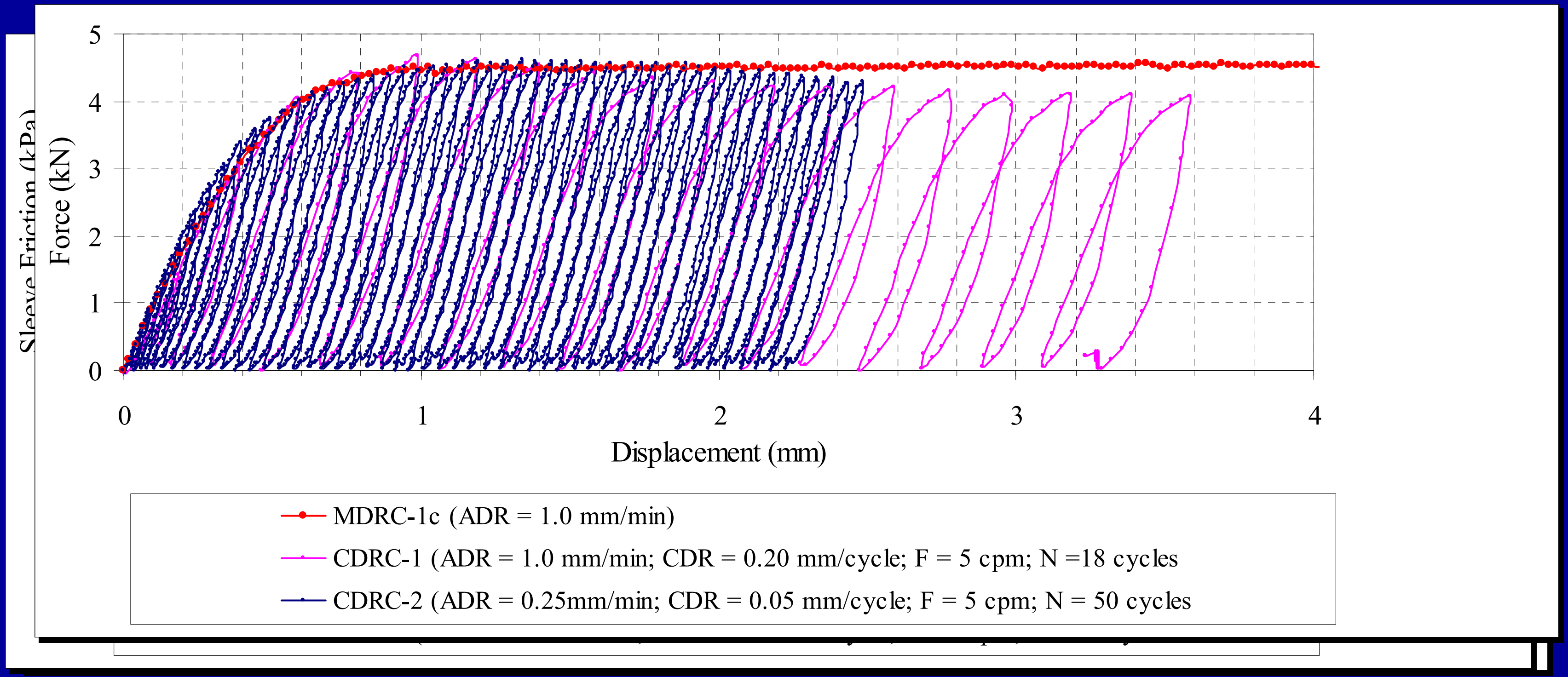
Initial Stiffness (Rate Effects)





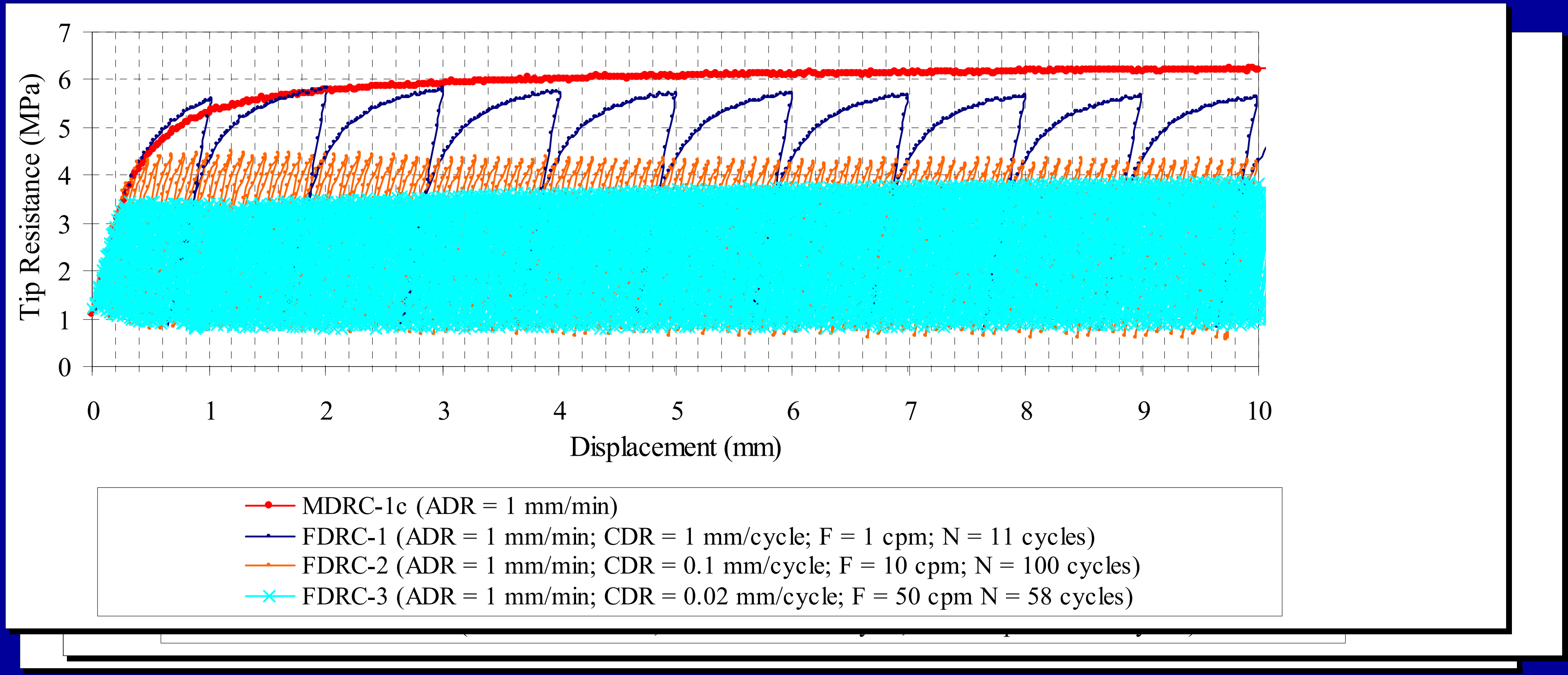
Loading

Cyclic Displacement Rate Control



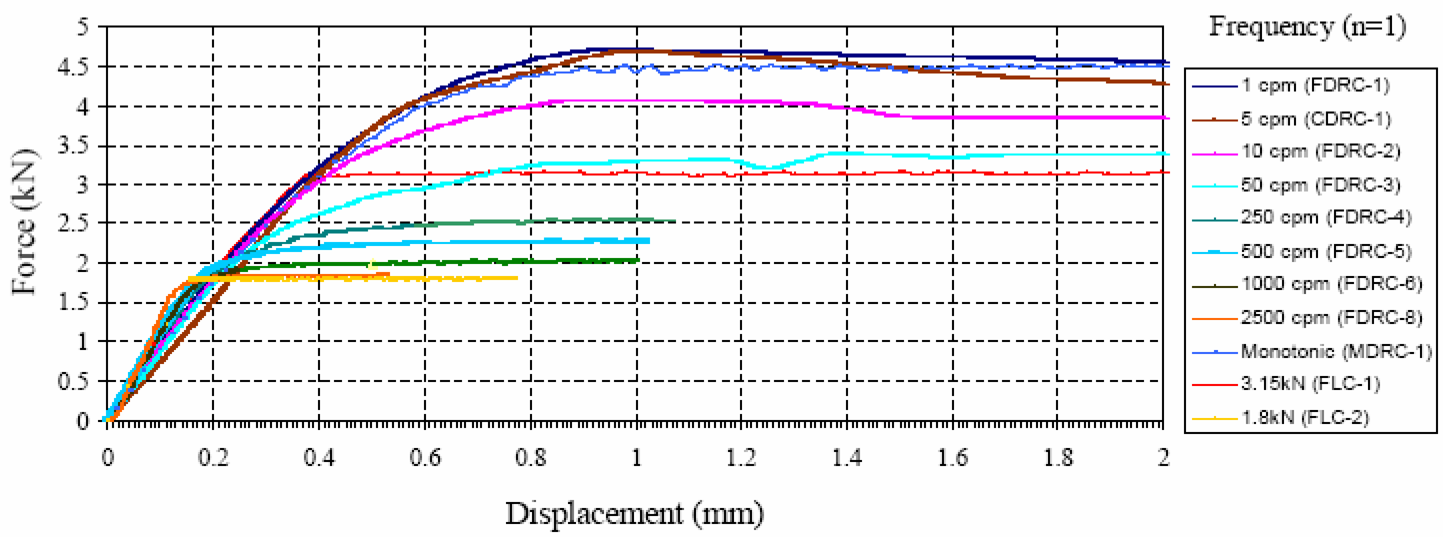
Variable Applied Displacement Rate

Cyclic Displacement Rate Control



Variable Cyclic Displacement Rate

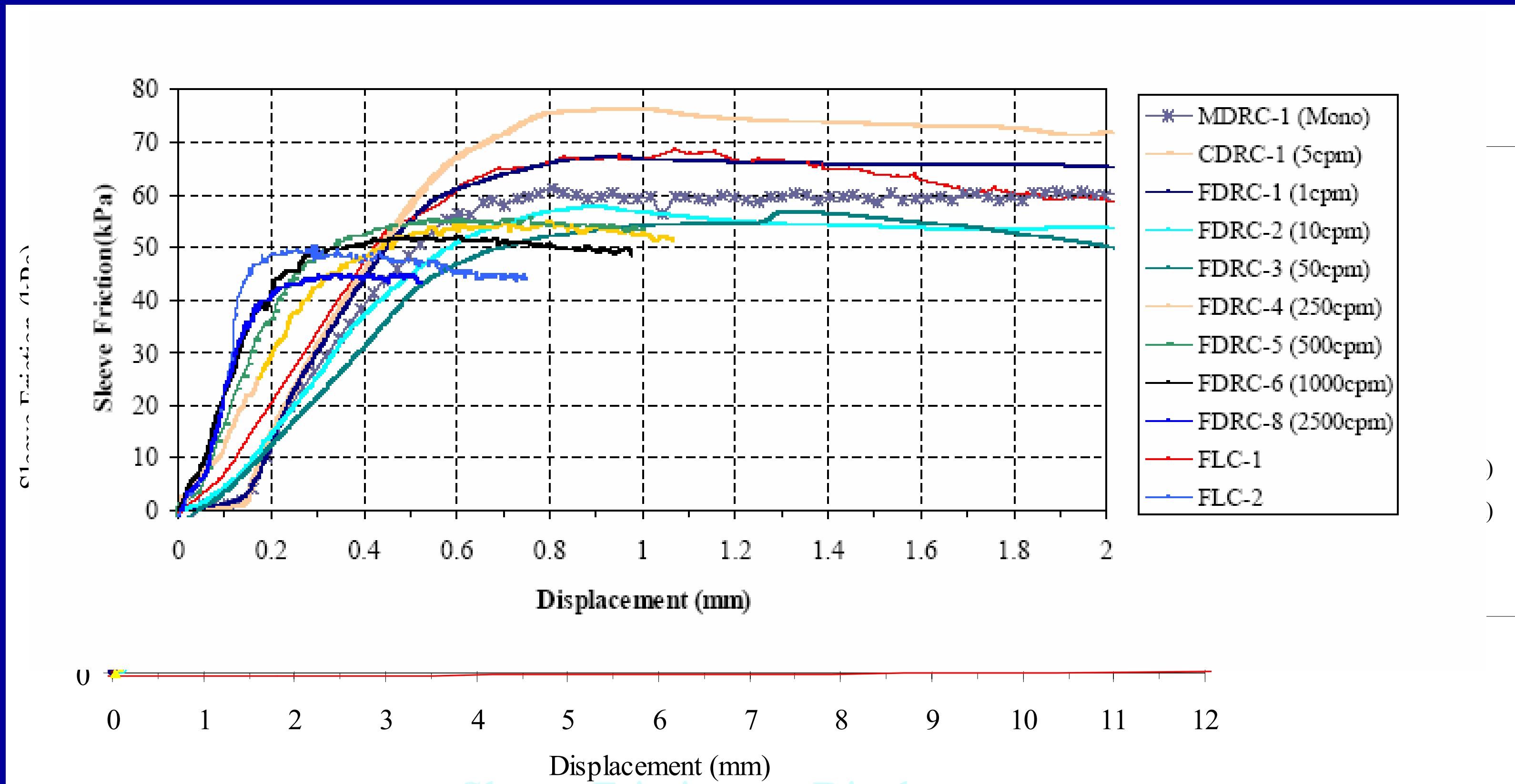
Cyclic Displacement Rate Control



Force vs. Displacement

Force vs. Displacement (cyclic envelope)

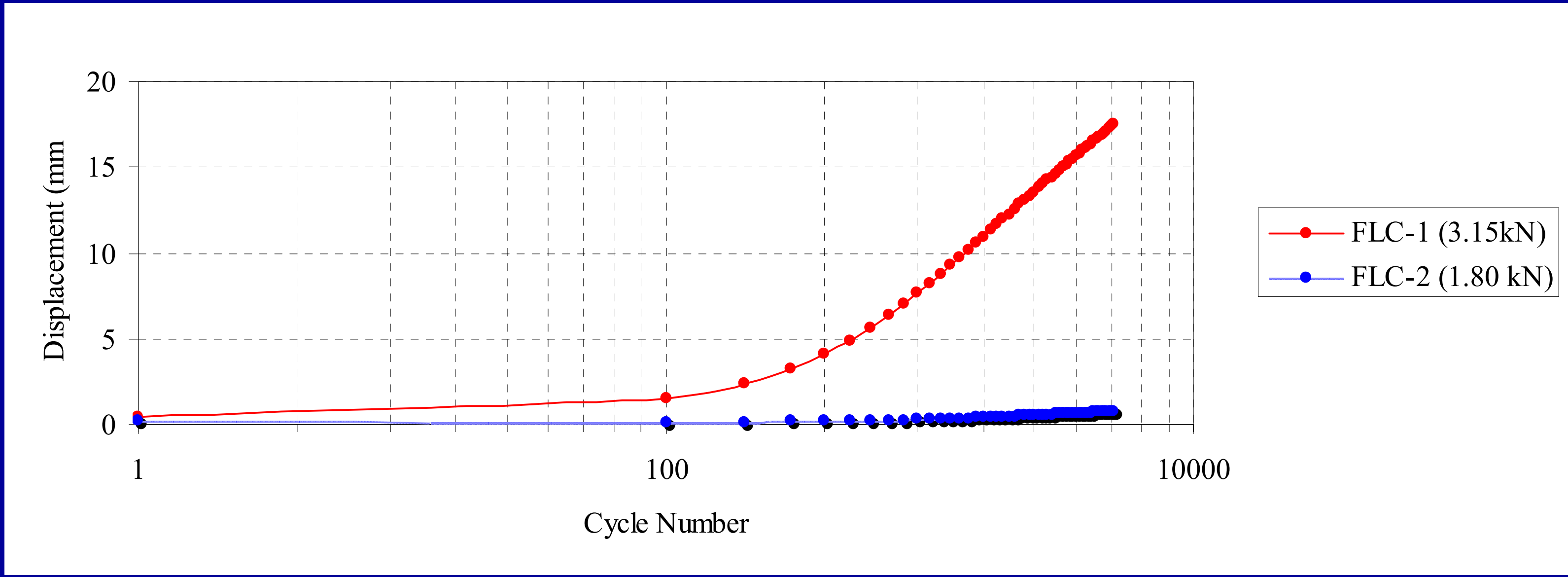
Cyclic Displacement Rate Control



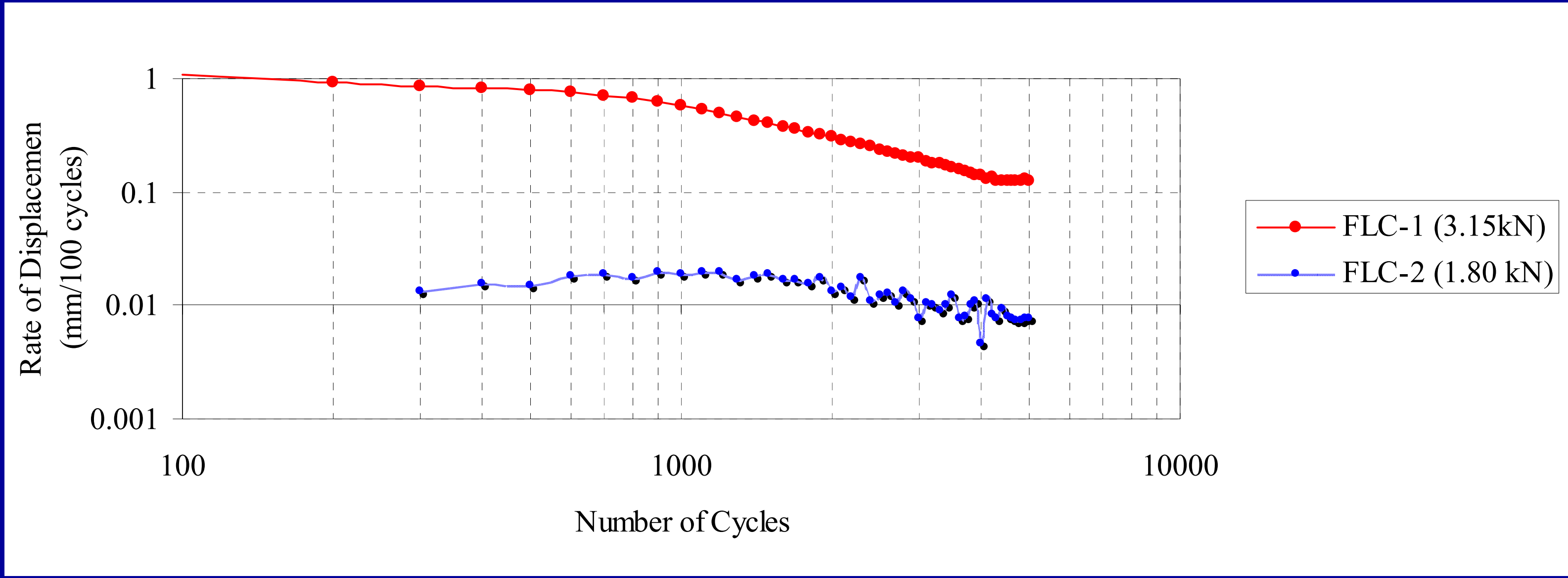
Sleeve Friction vs. Displacement

Sleeve Friction vs. Displacement

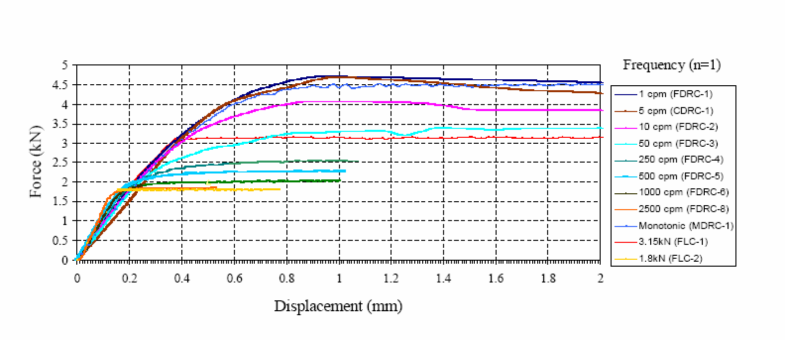
Load Control



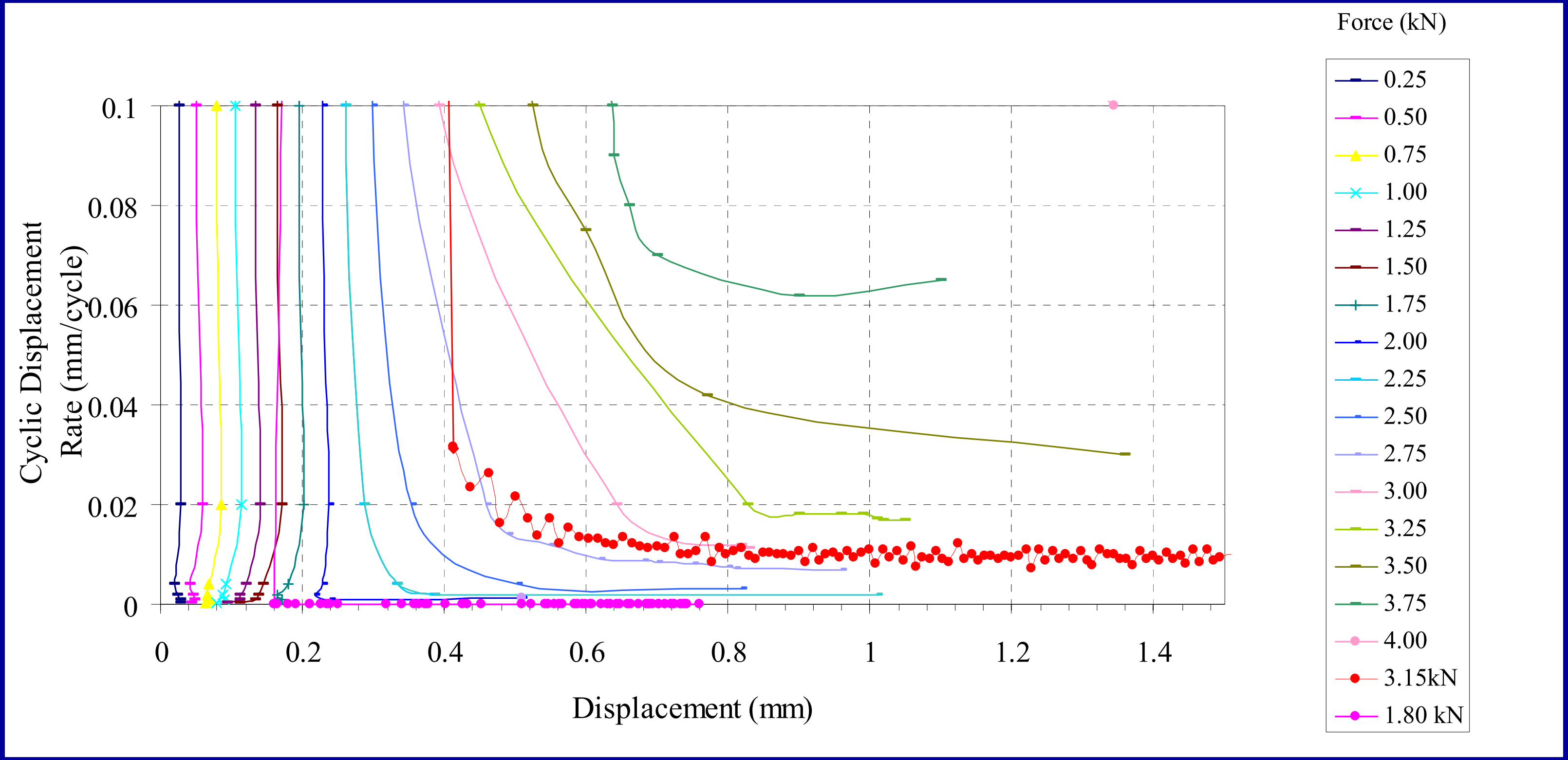
Displacement vs. Cycle Number



Displacement Rate vs. Cycle Number



Load & Rate Control



Displacement Rate vs. Displacement

Establishment of Critical Cyclic Load

Conclusions

- **Experimental Model Evaluation** illustrates that model predictions agree with the experimental results indicating that long-term behavior of strain-rate dependent and frequency dependent materials and phenomena such as soil-pile interaction can be predicted using short-term strain rate controlled cyclic compression test results.

- **The cyclic strain model predicts** a Cycle Limit at which the cyclic strain process ends for loads that are smaller then the Critical Cyclic load. For loads that are greater than the Critical Cyclic Load, the model predicts linear long-term strain-cycle behavior.

- **Further research** is now required to better understand the effect of in-situ testing conditions (i.e. soil confinement, ground water, etc.) on the long-term cyclic behavior of micropiles. **Full scale loading tests would be required** in order to provide a relevant database for the field evaluation of the strain rate – cyclic creep model and the development of reliable design methods for the assessment of the long-term performance of rate and frequency dependent phenomena.
- **Impact on Engineering Practice** Existing pile load testing equipment could be used to conduct full-scale field loading tests using the suggested testing protocol. If successful, testing standards could be developed which could lead to adopting the proposed cyclic strain testing procedure and strain rate controlled cyclic strain model as a base line for industry pile testing standards

Research Program Support

Schnabel Engineering
Polytechnic University
International Association of Foundation Drilling (ADSC)

Applied Geotechnical Engineering (AGE)
Branlow Piling Solutions
CAT Construction/Traylor Group
Con-Tech Systems LTD.
DBM Construction
Geosystems LP
Hayward Baker, Inc.
Ischebeck
Layne GeoConstruction
Moretrench American Corp.
Nicholson Construction
TEI Rock Drills

Thank You