Application of Stress-Wave Theory to Piles, Niyama & Beim (eds) © 2000 Balkema, Rotterdam, ISBN 90 5809 150 3

Results of an international pile dynamic testing prediction event

A. Holeyman
Université Catolique de Louvain, Louvain-la-Neuve, Belgium

J. Maertens
Katholieke Universiteit Leuven, Leuven, Belgium

N. Huybrechts & C. Legrand
Belgian Building Research Institute, Brussels, Belgium

ABSTRACT: An international prediction event was carried out within the framework of a 30-pile testing program organized in Belgium. That program called upon several testing methods: static load tests, Statnamic testing, and dynamic testing. This paper provides a summary of received predictions and results obtained from the static pile load tests, which were carried up to failure of the instrumented piles. The comparison between predictions is made using load-settlement curves with reference to the results of the static load tests. A companion paper reports on the project background information that was required to prepare the prediction event, including a description of the pile types and results of an extensive soil investigation program.

1 INTRODUCTION

1.1 *Program Background*

A national research project has been organized by the Belgian Building Research Institute in order to establish the performance of different types of cast-in-place ground displacement screwed piles. The program included the installation and testing of 30 test piles that allowed the organization of a prediction event. That prediction effort was undertaken with the hope to document the profession's ability to estimate these new piles behavior based on standard investigation means as well on dynamic testing.

Six different types of ground displacement piles were installed (five of each) and tested: one prefab and five cast-in-place screwed types: Atlas, De Waal, Fundex, Olivier, and Omega. An extensive soil investigation was performed as part of the research project, including in situ tests (CPT, PMT, SPT, DMT, SASW) and laboratory tests on undisturbed samples.

1.2 *Prediction preparation*

A project synopsis had been prepared to invite interested parties to make those predictions (Holeyman et al, 1999a). It included a description of the pile types, site characterization, the static load test procedure, the dynamic load test procedure and the format of the prediction.

Interested predictors were sent the complete information, available as laboratory and in situ investigation and dynamic load test results (Holeyman et al, 1999b). Predictions could be established based on the dynamic load tests, the geotechnical investigation, experience, or a combination of the above.

The piles types, layout, and the site investigation are described in a companion paper (Holeyman et al, 2000). The present paper focuses on load tests results and their comparison with results of the static load tests.

2 DYNAMIC LOAD TESTS

2.1 *Procedure for dynamic load tests*

The loading device used to impact the 12 piles installed for that purpose was a 4 tons drop hammer operated by a crane. A sequence of several blows was applied to each pile. The drop height sequence most often applied was as follows: 0.40m, 0.80m, 1.2m, 0.8m, and 1.2 m.

Dynamic measurements of strain and acceleration were acquired for all 12 piles using a TNO FPDS5 system. In addition 6 piles were also monitored using a PDI PDA-PAK system (Prefab, Fundex, and De Waal piles) and one Omega pile was monitored using a PDI PAL system. A 0.4m-diameter head was cast on July 6^{th} on top of the 10 cast-in-place piles. The transducers were attached generally 0.8 m from the top of the approximately 1.5 m high head. Displacements were acquired using a laser system.

2.2 *Distribution of dynamic load test measurements*

The results of dynamic load test measurements (pile head force, velocity and displacement) were made

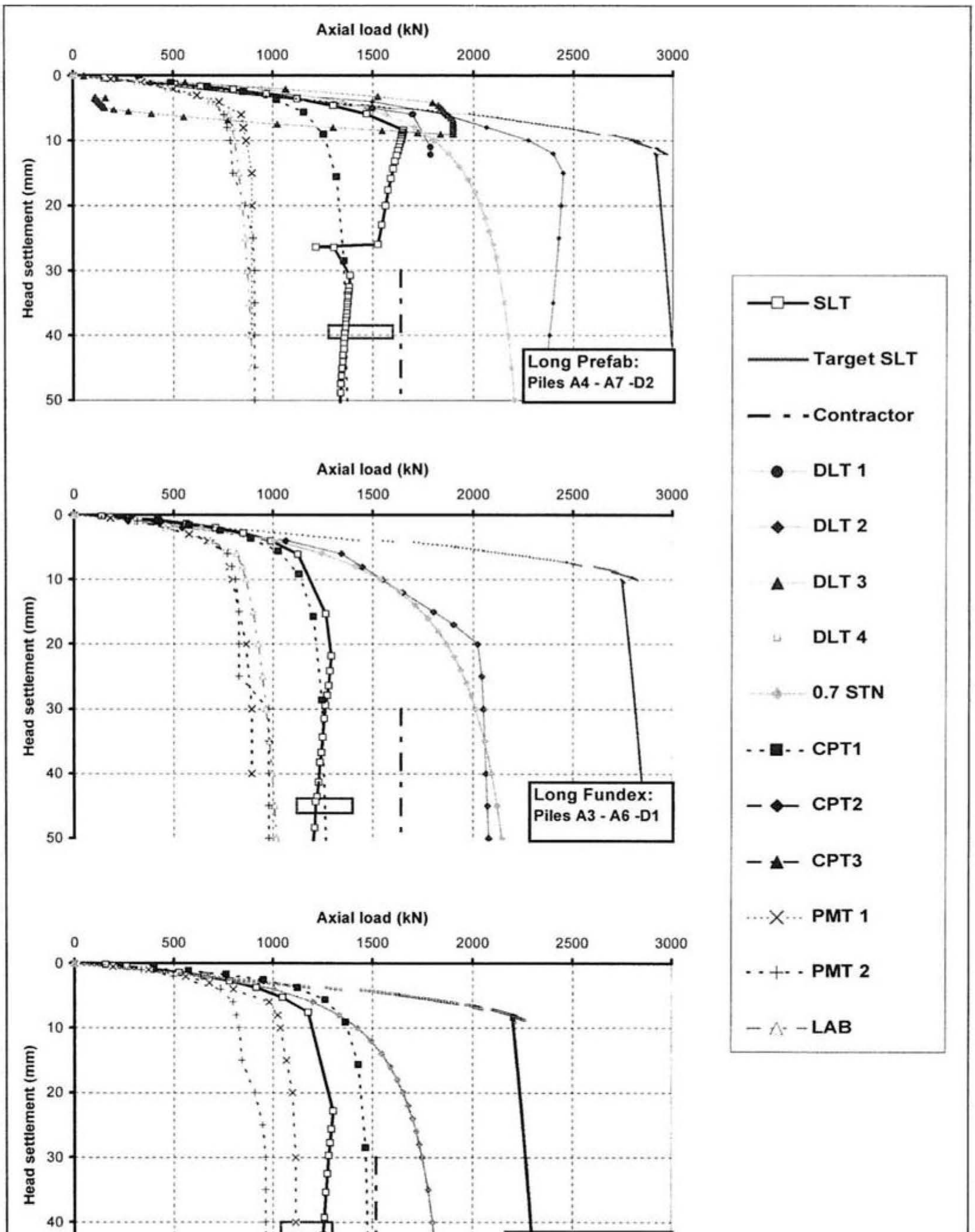

Figure 1a : Long Piles Load Settlement Curves – Prefab, Fundex and De Waal

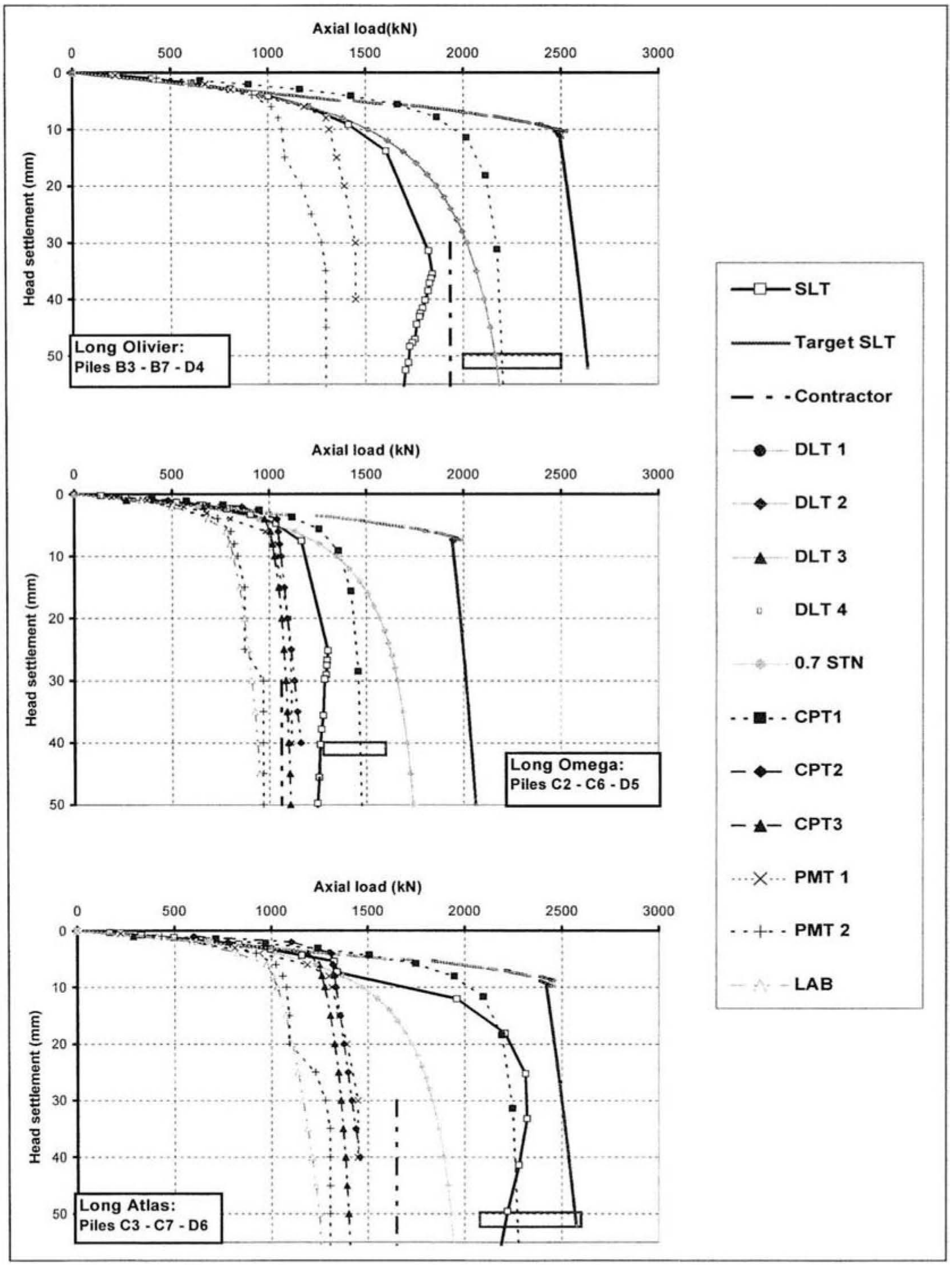

Figure 1b : Long Piles Load Settlement Curves – Olivier, Omega and Atlas available under a digital format to parties that had expressed an interest to make a prediction on that basis. Also characteristics needed to interpret the measurements were provided in part in Table 1 of the companion paper (in particular dimensions and properties of the pile heads extension) and in part in the files containing the measurements. Additional characteristics (wave propagation speed, density, pile impedance, etc.) needed to further analyze the measurements were distributed together with the measurements.

Interested parties obtained the digital files of the events by e-mail, which required the structuring of a vast amount of information, totaling more than 8 Mbytes of digital records. For each pile type a directory was established (for example the Prefab directory), containing subdirectories according for each pile of that specific pile type. The 'pile number' subdirectory (for example subdirectory pile A7 in the directory Prefab) contained a word file: (e.g. 'A7info.doc') and was further subdivided into the following subdirectories: TNO files, ASCII files, PDA files, and Displacement files. The word file 'A7info.doc' gave supplementary information about the dynamic load test on the pile A7 (the blow numbers, the drop height, and field notes). It was thus possible for the predictors to reprocess the raw signals using adjusted pile parameters, number of samples, etc.

2.3 *Measurements nominal interpretation*

The choice of the relevant moduli and sections is often considered as part of the predictors' art and was purposely left open to some degree, as is usually the case for cast-in place piles.

It was emphasized that all files had been uniformly acquired using a nominal modulus of approximately 40,000 MPa and a nominal wave speed of 4,000 m/s at the measurement section (i.e. in the concrete of the cast head). The pile heads were cylinders with a diameter of 0.4 m, except for the Prefab pile where the current 0.35x0.35m section prevailed. It was the predictor's responsibility to assess the measurement section modulus adequate for his prediction. It was also emphasized that the concrete of the tested pile below the added head had a different modulus and a different section. It was also the predictor's responsibility to assess the appropriate section and modulus for the shaft.

Peripheral information allowing the predictor to perform that important assessment included Table 1 of the companion paper, the digital signal themselves (e.g. impedance match or 2L/c check), integrity tests of the piles. Strength and ultrasonic wave speed measurements on concrete samples cast at the time of installation of the piles and concreting of the pile heads were made available finally. Low strain testing had been performed on all piles both the BBRI and CEBTP and results provided to predictors.

3 RECIEVED PREDICTIONS

3.1 *Reporting format*

The predictions are reported herein under an anonymous format in order not to stigmatize those with less accurate predictions. Each prediction is however labeled with a code corresponding to the prediction type. Each predictor is thus enabled to position his own prediction within the cluster of results and encouraged publishing his prediction procedure, using the present paper as a reference.

3.2 *Predictions types*

Results from 10 predictors had been received on November 5th 1999, the ultimate submittal date. Contractors had also predicted the ultimate bearing capacity of their own piles (they were not asked to supply the load-settlement curves.)

According to the reference data used to cast those predictions, the following labels have been used:

- "CPT" for predictors using the CPT results.
- "PMT" for predictors using the PMT results.
- "LAB" for predictors using the laboratory results.
- "DLT" for predictors using the Dynamic Load Test results.
- "STN" for predictors using the Statnamic Test results.

The CPT predictors used different methods, including ultimate state design as well as load transfer curves. All the contractors' predictions were made using CPT results and De Beer's 1974 method. The PMT predictors used the pressiometric approach that provides stress-displacement relationships for the shaft and the base. The LAB predictor used a load-transfer functions method based on plasticity indices.

The DLT predictors' methods included either CAPWAP or SIMBAT: the soil parameters in a model are adjusted to get the best match between the measured and the predicted signals of a Dynamic Load Test. SIMBAT is an empirical method converting the dynamic reaction to a static reaction.

The STN predictor used the Unloading Point Method (UPM) to predict the static load test. It was mentioned by the predictor that, due to strain rate sensitivity of clayey soils, a 30% reduction coefficient had to be applied on the usual UPM method. A hyperbolic approximation of that reduced function was then calculated. This is the reason why those predictions are labeled as "0.7 STN".

It should be noted that the STN predictor was not provided with the results of the dynamic load tests, and that no TNO-WAVE prediction was submitted.

3.3 *Predictions classes*

Predictions had to be made *before* static pile load tests were performed in order to qualify as Class A type predictions. If predictions were made *after* the static pile load tests, they qualified as C type predictions, according to accepted definitions of predictions classes (Lambe, 1973).

Each prediction for each pile can be classified according to its submittal date relative to the date of static loading. Table 1 shows that most of the predictions are Class C. The only Class A predictors were CPT 1 (except for piles A1 & A4) and Contractors Atlas and Fundex. Other Class A predictions were those of predictor DLT2 for A3 pile and of predictor PMT1 for C2 to C4 piles.

4 STATIC LOAD TESTS

4.1 *Procedure for static load tests*

The static pile load tests were to comply with the following loading guidelines, referring to Q_{max}, the maximum anticipated test load, chosen with the hope to cause bearing failure:

- A pre-load stage of maximum 5% of Q_{max} was applied in order to check the measurement equipment and the centricity of the applied force,
- 10 maintained load steps with equal ΔQ until Q reaches Q_{max}
- No intermediate unloading cycles
- Duration of maintained load step of 60 minutes
- Load test was performed until a pile head settlement $\geq$ 15% $\varnothing_{base}$ was reached
- When the pile head settlement has reached a value of 25 mm, subsequent load steps can be applied using a smaller increment ($\Delta Q/2$), in order to refine the pile load-settlement curve as it approaches failure,
- Unloading in 5 steps of 10 min. each, except for final unloading (30 min at least of monitoring).

The system used to apply the maintained loads on the piles called upon a sophisticated hydraulic regulation that guaranteed a tolerance of 5 kN. That system had just been developed by the BBRI. The 3 MN reaction was provided by a kentledge consisting of concrete blocks. Besides load and settlement monitoring, extensometers provided longitudinal strains along 5 to 7 shaft segments along the pile length. The results provided by those more detailed measurements are to be reported elsewhere.

Such a procedure requires a value for the ultimate capacity R_u of each pile. Those capacities were estimated by the BBRI and the national experts using De Beer's method based on the CPT tests results (De Beer, 1974). The load increments ΔQ were actually:
- $R_u/8$ for Atlas, Fundex, Prefab and Olivier piles.
- $R_u/10$ for De Waal and Omega piles.

The ultimate capacity was considered reached when the pile head settlement was equal to 10% $\varnothing_{base}$. It should be noted that a maximum Constant Rate of Penetration (CRP) of 0.6 mm/min was enforced towards the end of the loading procedure for all piles (except for piles A1 and A4).

4.2 *Results*

Figures 1 and 2 show the various load (Q) – settlement (s) curves for the long and the short piles, respectively.

"SLT" refers to the Static Loading Test. The predictors' curves are also identified using the labels discussed in Section 2.2. "Contractor" refers to the ultimate capacity predicted by the Contractor. This value is drawn for 30mm < s < 50mm with a bold line. "Target SLT" refers to the ultimate capacity estimated by the BBRI. It is a "box" corresponding to:
- $8\,\Delta Q < Q < 10\,\Delta Q$
- $9.75\,\%\,\varnothing_{base} < s < 10.25\,\%\,\varnothing_{base}$

5 DISCUSSION

The load-settlement curves resulting from the static load tests show a good proportionality between load and settlement up to 5 mm settlement. Beyond that point, the curves deviate from their initial linear trend. After evidencing a peak resistance, the pile settles under a slowly decreasing load beyond settlements exceeding 10 to 20 mm.

Pile C3 exhibits an unusually high peak, with the load increasing very rapidly up to about 2300 kN within a 6 to 20 mm settlement range. This was due to a problem in the pressure regulation of the hydraulic jack. After reaching a settlement of 6 mm, the pile started to settle at a rate of penetration of approximately 48 mm/min. This explains that the peak capacity of the SLT (about 2300 kN) is an overestimate of the pile ultimate static bearing capacity. In the absence of that regulation problem, the peak would have been reached under a load of approximately 1500 kN. This test evidences the influence of the rate of penetration on the assessment of piles ultimate bearing capacities.

PMT and LAB predictions are consistently on the safe side of the SLT curve. PMT1 and PMT2 curves are very similar, which tends to show that the pressiometric approach is consistently applied.

BBRI predictions (targets "windows") were good except for Piles B3, B4, C1 and C4 where the ultimate capacity had been overestimated.

CPT1 predictions were extremely accurate for, A1 to A4 but overestimated the results for B and C piles, probably because of an overestimated installation coefficient.

Concerning the DLT and STN predictions, it can be observed that maximum transient pile displacements rarely exceed 15 mm That might explain why

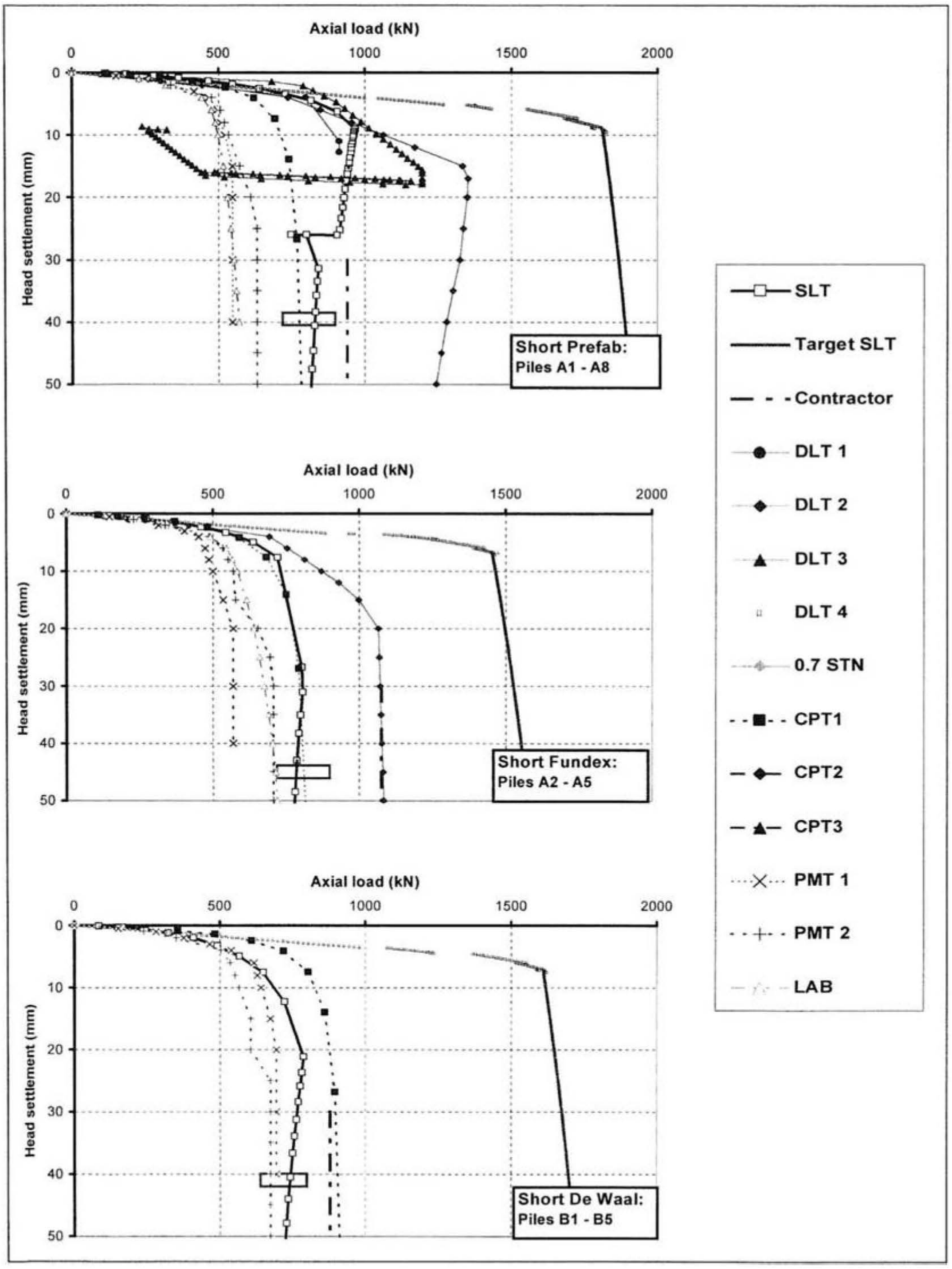

Figure 2a : Short Piles Load Settlement Curves – Prefab, Fundex and De Waal

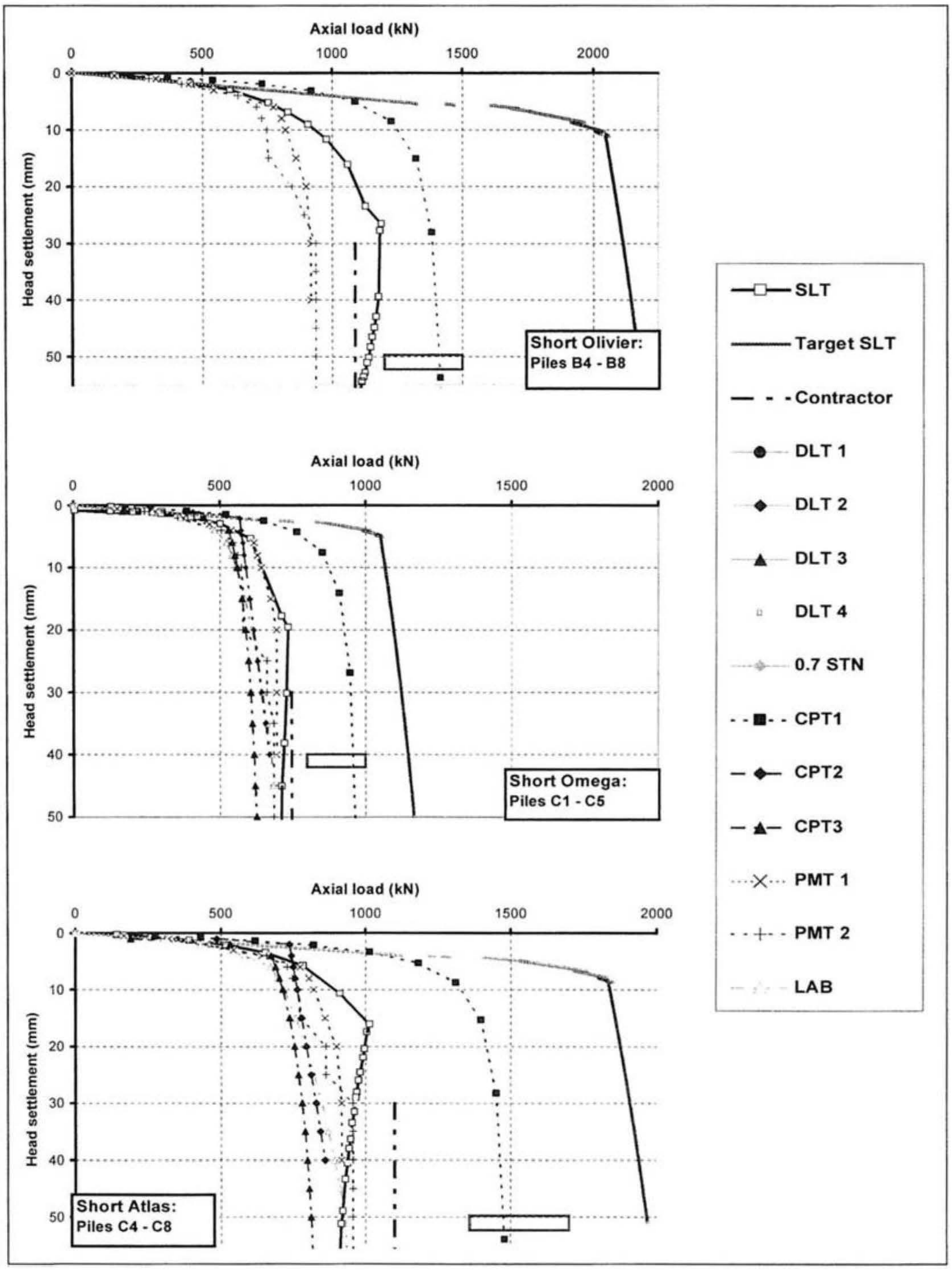

Figure 2b : Short Piles Load Settlement Curves – Olivier, Omega and Atlas

Table 1. Predictions classes

	Pile	Long Prefab	Long Fundex	Long De Waa	Long Olivier	Long Omega	Long Atlas	Short Prefab	Short Fundex	Short De Waa	Short Olivier	Short Omega	Short Atlas
	Static Test Date	30/8	15/9	17/9	23/9	5/10	12/10	2/9	7/9	15/9	21/9	30/9	7/10
	Submittal Date												
Label													
CPT 1	5th Sept 99	C	A	A	A	A	A	C	A	A	A	A	A
DLT 1	9th Sept 99	C						C					
DLT 2	10th Sept 99	C	A					C	C				
DLT 3	1st Oct 99	C						C					
PMT 1	4th Oct 99	C	C			A	A	C	C			C	A
LAB	27th Oct 99	C	C	C	C	C	C	C	C	C	C	C	C
PMT 2	28th Oct 99	C	C	C	C	C	C	C	C	C	C	C	C
CPT 2	29th Oct 99					C	C					C	C
CPT 3	29th Oct 99					C	C					C	C
DLT 4	5th Nov 99	C	C	C	C	C	C	C	C	C	C	C	C
STN	5th Nov 99	C	C	C	C	C	C						
Contractor													
Fundex	12th Aug 99		A						A				
Franki	26th Aug 99						A						A
Socofonda	3rd Nov 99					C						C	
Olivier	4th Nov 99				C						C		
De Waal	5th Nov 99	C		C				C		C			

those methods encounter more difficulties in predicting pile behavior under large displacements. The predictions (DLT1 to 4 and 0.7 STN) are quite good within the service load range of the load-settlement curves. DLT1 and DLT 3 are very close to the SLT ultimate capacities even though they did not predict the pile behavior for settlements greater than 20 mm. DLT2 (Capwap method), DLT4 (Simbat) and 0.7 STN overestimates of the ultimate capacities would warrant the following approximate reductions:

- DLT2 by 25 %,
- DLT4 by 50 %.
- 0.7 STN by 25 % (which means the 30 % reduction coefficient initially taken by that predictor should have been 50 %).

If such reductions were applied to these predictions, they would however not fit as well the initial part of the SLT curves. The reduction of dynamic soil resistance to its static value still needs to be clarified.

6 ACKNOWLEDGMENTS

The authors would like to acknowledge the Belgian Ministry of Economic Affairs for its financial support of the testing program (Convention CC CIF – 562). The 'De Nayer' Institute at Sint-Katelijne-Waver made the test site available. Contractors installed their own piles free of charge. Profound performed the Statnamic tests and CEBTP the integrity tests also free of charge. Dr. Klingmuller, of GSP, Mannheim loaned a PDA while TNO provided an FPDS5 system free of charge. Bachir Dali, Paris, using an in-house laser system he developed, acquired displacements on a voluntary basis. The authors would like to thank Mr. J. -M. Couvreur, Research Assistant at UCL, for his management of communication with the predictors and of the information, including preparation of comparative figures. Finally this exercise would not have been possible without countless hours accrued amongst the several prediction team that bravely took up the challenge. Many thanks to those heroes; some of who will hopefully identify themselves through follow-up publications.

7 REFERENCES

Lambe T.W. (1973), Predictions in soil engineering, Géotechnique XXIII, n°2, p 149-202.

Holeyman, A. et al., Design of axially loaded piles - Belgian practice in *Design of axially loaded piles - European Practice*, edited by De Cock and Legrand, Balkema, Rotterdam, 1997, pp.57-82

Holeyman et al (1999a), Prediction Invitation, Belgian Research Project "Ground Displacement Screwed Piles at Sint-Katelijne Waver", August 20th 1999.

Holeyman et al (1999b), Additional Reference Document for Predictors, Belgian Research Project "Ground Displacement Screwed Piles at Sint-Katelijne Waver", August 29th 1999.

Holeyman et al (2000), Preparation of an International Pile Dynamic Testing Prediction Event, Proceedings of the VIth SWC, Sao Paulo.