SIMBAT DYNAMIC PILE TESTING - RESULTS OF AN INDEPENDENT PILE CAPACITY PREDICTION EVENT.

Richard T. Stain, Testconsult Ltd, Warrington, UK

In 2001, a pile trial site was established at Limelette in Belgium consisting of 25 displacement screw piles and 5 driven pre-cast piles. Interested parties were invited to participate in a pile prediction event, whereby they would submit predicted static load test behaviour in the form of load settlement plots. These predictions could be based on soil investigation results supplied by the organizers, or dynamic load test measurements.

Following the submission deadline, the organisers released the results of static load tests for comparison.

Of all the six participants, including Statnamic, the SIMBAT method was independently accredited with achieving the best predictions.

This paper examines at the differences between SIMBAT and other systems, and presents the correlations from the Limelette trial.

INTRODUCTION

The Belgian Building Research Institute (BBRI) initiated an ambitious research programme involving the construction and testing of some 60 trial piles spread between two sites, a clay site at Sint Kateline Waver and a sandy site at the BBRI headquarters at Limelette. The project was financed largely by the Belgian Ministry of Economic affairs. (ref 1.) This paper refers only to the second site.

At Limelette, six different types of displacement pile were installed: one driven pre-cast and five cast in place screw piles - Atlas, DeWaal, Fundex, Olivier and Omega. A detailed site investigation was carried out including in-situ and laboratory tests.

An international pile capacity prediction event was publicised, participants being invited to predict static pile behaviour. Predictions could be based on:

- Site investigation data including in-situ and laboratory soil tests
- Dynamic load test data acquired by the organisers using PDI equipment
- Participants own test data

Dynamic load tests were carried out during a two day period on twelve piles using a 4 tonne drop weight and guide tube. Three sets of data were acquired simultaneously:

- by the organisers, using PDI equipment
- by Profound using TNO equipment
- by Testconsult using SIMBAT equipment.

The piles were static load tested and the results of these tests made available to participants only after submission of their predictions. 14 sets of predictions were received and of these 6 were based on dynamic testing. The results and correlations for the Limelette site were reported by Prof A. Holeyman and N.Charue (ref 2) in a symposium in Brussels May 2003.

This paper concluded that based on dynamic measurements, “DLT1 (SIMBAT) prediction can be considered as the fittest for all piles”

It should be noted that in this paper all predictors are anonymous, being referred to as DLT 3 for example. Testconsult, using SIMBAT was referred to as DLT 1 and Statnamic was obviously identifiable, being referred to by that name.

This paper describes the SIMBAT methodology and highlights the differences between it and other techniques. The SIMBAT predictions and correlations are presented and discussed.

THE SIMBAT METHODOLOGY

The SIMBAT methodology was developed by J.Paquet, research manager at the CEBTP in France and first published in 1988 (ref 3). In that paper, a clear differentiation was made between measuring pile capacity <u>during</u> driving as in pre-cast piles, and measuring capacity <u>after</u> installation. In France, very few pre-cast driven piles were installed and the SIMBAT methodology was designed particularly for bored, cast in place piles.

The general methodology of dynamic pile testing is well known so it is only intended here to highlight the differences between SIMBAT and other systems.

These differences are:

- free fall impact mass
- theodolite to measure displacement
- electrical resistance strain gauges
- drop height sequence.

Impact mass

Because SIMBAT is primarily used and indeed designed for bored piles, there is normally no driving hammer or mass available on site. This has led to a range of purpose-designed free fall drop masses. These can vary from 60Kg (Fig 1) designed to be operated manually by two men, through to the largest used yet, a 35 tonne, segmental mass for large diameter bored piles.(Fig 2)

Fig 1. 60Kg drop mass for micro piles

Fig 2. 35 tonne drop mass (Taiwan)

The correct choice of a suitable mass for the pile to be tested is a delicate balance between sufficient size and least cost for transportation etc. The best mass is one that will cause a permanent displacement at the pile head of about 5 mm for a 2 – 2 .5m free fall. Drop heights greater than that should be avoided as they cause very high acceleration and velocity at the pile top with the consequent risk of the pile head bursting under the impact. The shape and duration of the impact is important and can be controlled to some extent by the cushion. A coil of rope is usually the most effective.

A common practice in Ireland is to cast into the pile a central reinforcing bar, projecting from the pile top by two or three metres. The impact mass, with a central hole is then allowed to slide on this bar thus ensuring both safety and a clean, axial impact.

Fig 3. Four tonne, concrete mass sliding on a central reinforcing bar. Foundations for Bridge over the River Liffey, Blackhall Place, Dublin.

Optical Theodolite

Implicit in the SIMBAT technique is the use of a non-contact theodolite to measure the pile displacement during the impact. The theodolite is based on the same principle as a modern day digital camera and incorporates a charge coupled device (CCD) which consists of 2048 separate light sensitive elements, each one being 14microns height. The ultimate sensitivity of the instrument depends on the distance to target, the larger the distance the lower the resolution. At 5m the resolution is 0.14mm, sampling frequency is 10,000Hz

The theodolite is normally placed between 5 and 10m from the pile and focussed on a small black/white target attached to the pile head. During the impact, the target moves with the pile and the whole of the deflection cycle is captured and stored on the data acquisition unit. This serves as an independent check on the velocity deduced from the accelerometers. In fact, velocity obtained by integrating acceleration is always incorrect due to the unknown integration constant. Likewise, displacement deduced from a double integration of acceleration is virtually useless because of the two unknown constants. It is only by using a device that measures the whole deflection cycle that accurate velocity and permanent displacement can be obtained.

Fig 4. Theodolite in use on Limelette site

Fig 5. Theodolite with 500m focal length lens

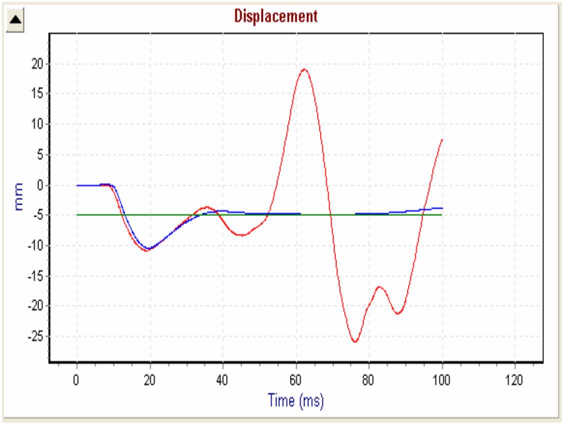

Fig 6. Pile top displacement diagram

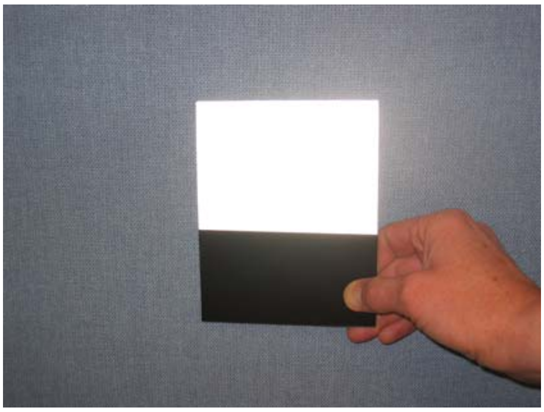

Fig 7. Reflective theodolite target

The displacement diagram (Fig 6.) shows three discrete lines, firstly the direct reading from the theodolite. This is recognisable as it has a sudden peak at 60ms where the ground wave radiating from the pile reaches the tripod which supports the theodolite. This effect is not welcome but neither is it too important as the dynamic displacement of the pile is obtained prior to the arrival of this ground wave. After the wave has passed and the instrument is stable, the permanent displacement is measured and shown as a horizontal line. Finally, the displacement obtained from the 2nd integral of acceleration is plotted and adjusted to match the both the initial, undisturbed portion of theodolite trace and the final, permanent displacement. By using this twofold approach a great level of confidence in the readings is established and, highly accurate data obtained. Accelerometers alone cannot do this.

Electrical Resistance Strain gauges

Total force in the pile top is measured using strain gauges. These are fixed to the side of the pile, about one diameter below the head. Two are normally used and are placed diametrically opposite. Most test houses use “bolt-on” gauges where the pile is drilled to allowing fixing with expansion bolts or similar. This is a convenient and economical method and the gauges can be re-used many times.

There are some drawbacks. The most significant is that the very part of the pile where strain is to be measured has to be disturbed by impact drilling to allow the fixing bolts to be placed. Inevitably, the holes themselves will create stress (and strain) concentrations leading to less than perfect conditions.

The SIMBAT technique utilises electrical resistance foil strain gauges and these are simply bonded to the side of the pile using a rapid setting epoxy resin. There is thus no disruption to the area where strain is to be measured. They cannot come loose, nor can they have stresses created during the bolting on process. They are always “in calibration” as they are always new and only used once.

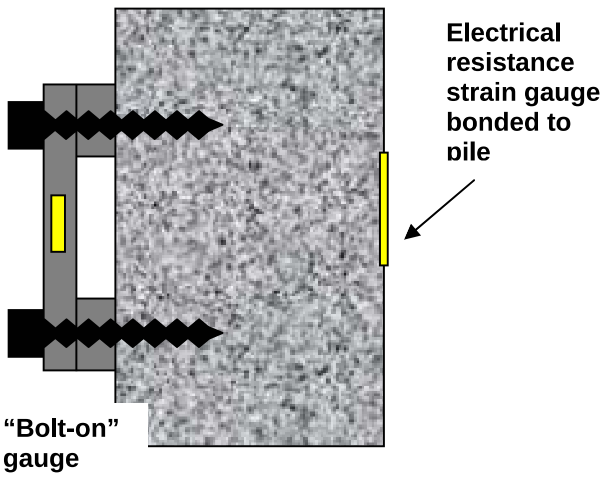

Fig 8. “Bolt-on” and Electrical resistance strain gauges

Hammer drop Sequence

All dynamic pile test methods require that dynamic values are converted to static reactions. This is frequently done by assuming an appropriate soil damping factor, J, in the CASE formula below:

$$\mathbf{R_{STAT} = R_{TOT} - Jc\,(Z.V_1 + F_1 - R_{TOT})}$$

Where:

R_{STAT} = static reaction
R_{TOT} = total reaction
Jc = soil damping constant
Z = Pile impedance
V = pile head velocity
F = Measured force

Paquet developed an alternative procedure which eliminated the need to assume a damping constant, rather a damping constant could be obtained by determining the single constant that fitted a whole series of blows. This series had to contain high, medium and low strain rates and was achieved simply by varying the drop height of the mass. The simple theory is that by obtaining dynamic (or total) reactions at these strain rates a projection back through zero strain rate would yield the static reaction. See Fig 9. below

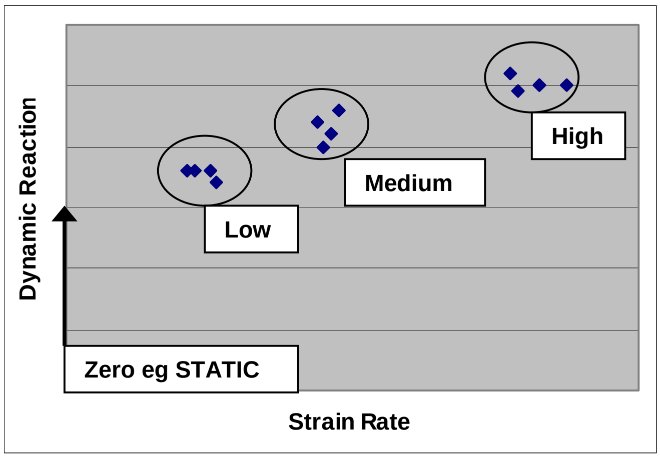

Fig 9. Simplified strain rate concept diagram

Drop Height (m)	Pile Head Displacement (mm)
0.4	0.12
0.6	1.08
0.6	0.98
0.8	1.44
1.0	2.27
0.6	0.72
1.2	2.47
0.8	1.56
1.4	2.87
0.6	0.0
1.6	3.47
1.0	0.60
1.8	3.47
2.0	4.19
2.2	4.70
2.4	5.87
1.0	1.68
2.6	6.94

Table 1. Typical Drop height/ pile top displacement.

A typical set of drop heights and permanent displacements is shown in Table 1. Of course, for each blow, a dynamic reaction Rdy is measured and these reactions are plotted against *cumulative* permanent displacement. (Note that some refer to Rdy as total reaction.)

These dynamic reactions are shown in Fig 10 as a dotted line. In the SIMBAT software, the soil damping factor can be adjusted for the whole set of data by moving the J slider which in turn creates a new plot (solid line) until a smooth curve connecting all points is obtained. It is visually apparent when the correct J factor is obtained, the result being a predicted static load displacement plot. While this is an empirical method, it has been shown to give good results in a wide range of soil types.

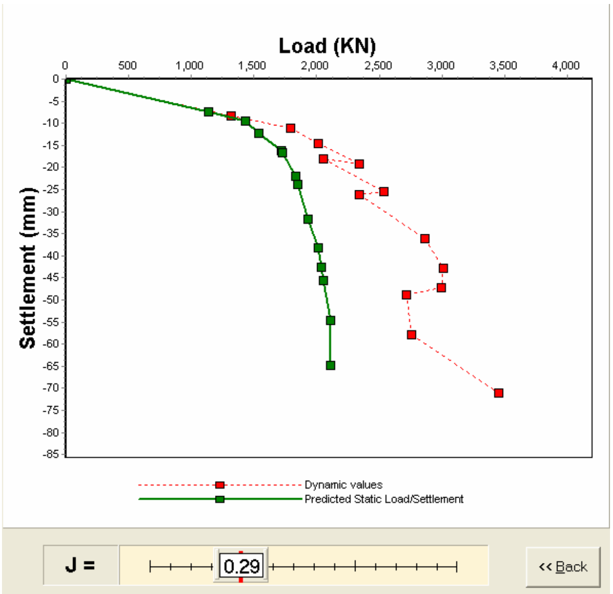

Fig 10. Dynamic to Static correction diagram

Normal practice would be to corroborate the static behaviour obtained in this way by injecting real measured force into the SIMBAT pile/soil model and adjusting the model until the calculated pile top displacement matches the measured pile top displacement (from the theodolite). The matching process is automatic but thankfully requires the intervention and judgement of an engineer from time to time. An example is given in Fig 11.

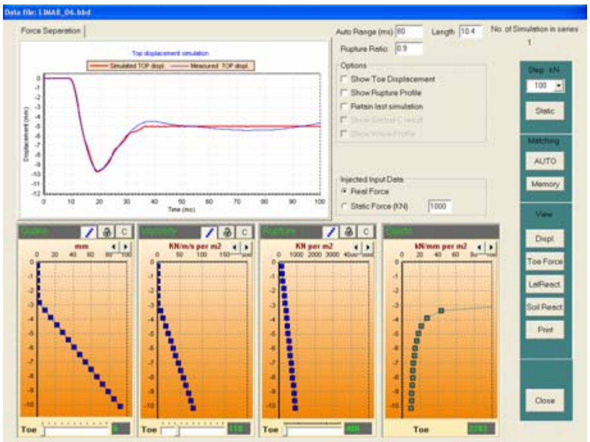

Fig 11. SIMBAT pile/soil model and matching software

LIMELETTE TRIAL

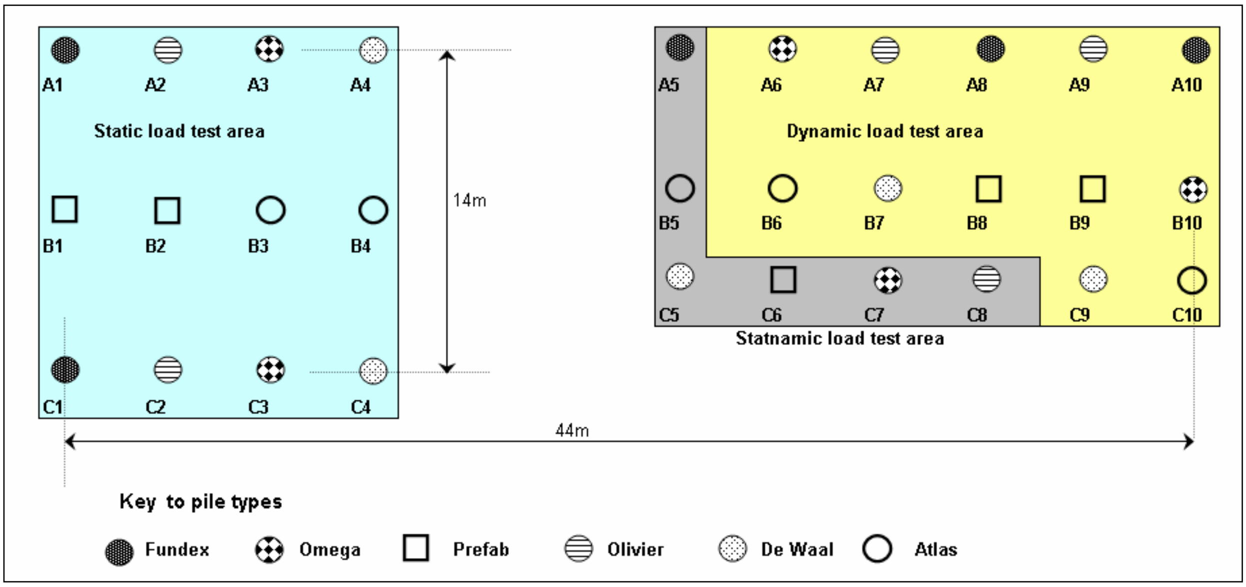

Fig 12. Piling layout at Limelette site

There have been a number of pile capacity prediction events and one of the earliest was at Ghent in Belgium in 1986 and reported by A. Holeyman (Ref 4). Since then there have been many others, notably work sponsored by the FHWA and reported by Clyde Baker in 1991 (Ref 5).

Such events never seem to be very conclusive, for one reason or another. There are numerous difficulties in obtaining true static/dynamic correlations, the most apparent being that once a pile has been loaded, either dynamically or statically, it is altered in the process. For example, if a friction pile in clay is tested statically on Monday, the chances are that it will have achieved a significantly increased capacity due to set up by the Tuesday when it is scheduled for dynamic testing. In the case of an end bearing pile in non cohesive soils, the capacity may well be increased by the additional penetration due to static loading.

It should be remembered that dynamic tests, like static ones, require quite large displacements to mobilise all the reactive forces, particularly at the pile toe. This “driving” effect will change the pile in the process of testing.

On the Limelette site, the organisers decided to construct identical twin piles, or rather identical quintuplets so that for each pile type, two were scheduled for static load testing, two for dynamic load testing and one for Statnamic testing. Of course, this approach suffers from the inevitable uncertainty of whether they were, in fact, identical or not.

A layout plan showing how the piles were constructed in separate areas for dynamic and static testing is given in Fig 12. This plan also highlights the pile types, so that it is easy to see, for example, that prefabricated piles, Pile B1and B2 were static load tested, C6 subjected to Statnamic and piles B8 and B9 for Dynamic testing.

With the exception of the prefabricated piles, all were displacement screw piles, and these different types are well described in Ref 6.

The dynamic load tests were carried out by three organisations simultaneously, Testconsult using the SIMBAT technique, TNO / Profound using FPDS5 system and by the organisers using a PDI PDA-PAK system. This meant equipping the pile tops with 6 strain gauges, 6 accelerometers and a theodolite target – rather crowded!!

Fig 13. Three sets of instruments being attached to pile top

Fig 14. Guide tube for 4 tonne mass.

The drop mass weighed 4 tonnes and operated inside of a guide tube attached to the pile top. This arrangement was highly satisfactory allowing a range of drop heights and clean axial impacts on the pile. The latter is always important to avoid tension forces on one side of the pile and damaging the pile head.

12 piles were tested during two days in October 2001, the participants then went away to mull over their data and to come up with static predictions before the deadline of 31st Dec 2001.

PREDICTION METHODOLOGY and RESULTS

The Testconsult methodology was firstly to consider the simple "driving record" for each pile. It is logical to assume that a plot of hammer drop height against penetration would yield interesting comparisons between the piles.

These graphs are given below, where it is apparent that the stiffest piles are the Atlas, followed by Olivier and so on. The Fundex piles showed a wide disparity. Pile A10 being considerably stiffer than A8.

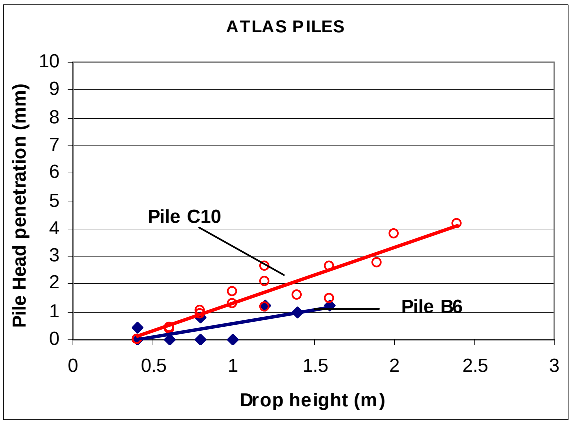

Fig 15. Atlas piles "driving record"

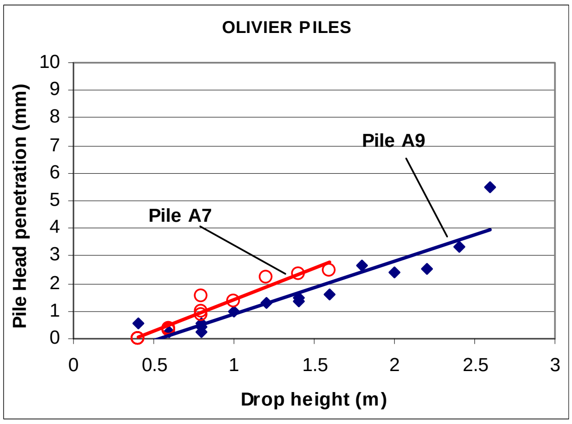

Fig 16. Olivier piles "driving record"

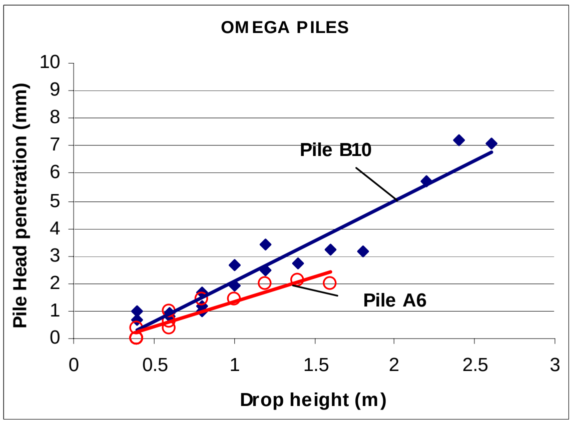

Fig 17. Omega piles "driving record"

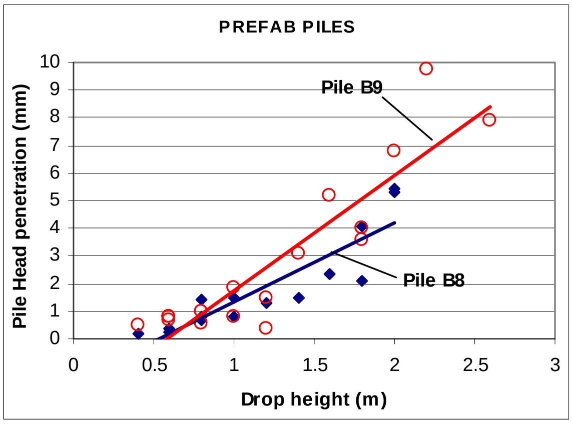

Fig 18. Prefab piles "driving record"

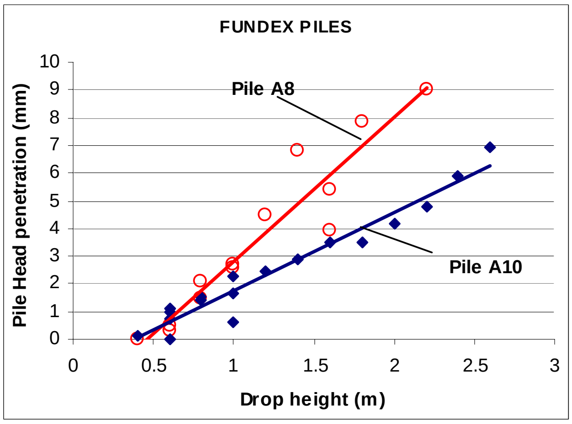

Fig 19. Fundex piles "driving record"

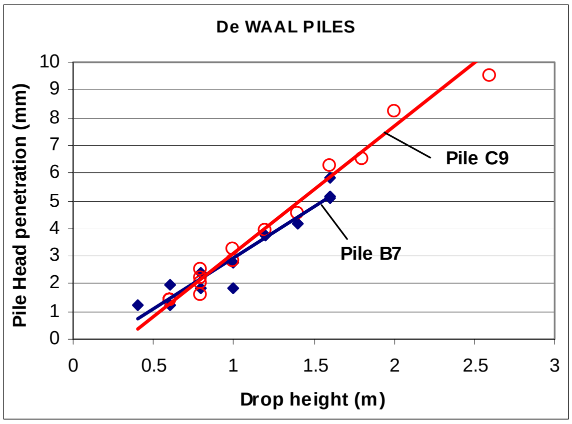

Fig 20. De Waal piles "driving record"

It is also apparent that these piles are not identical twins. The reasons for this are not known.

The dynamic data were interpreted in the normal way following the SIMBAT procedure.

- Correction of velocity using the theodolite as an adjustment signal
- Separation of force measured at the pile top into upward and downward components
- Calculation, for each blow, of the dynamic (or total) reaction, Rdy
- Plot of Rdy versus cumulative penetration for the whole set of blows
- Conversion to Static using the procedure described above.
- Verification of the static plot by modelling.

This latter step is important and uses the measured force (from strain) as the input signal and the pile head displacement (from the theodolite) as the adjuster signal.

The predictions submitted to the organisers are given below for each pile type and can be compared with the two static test results and the Statnamic results.

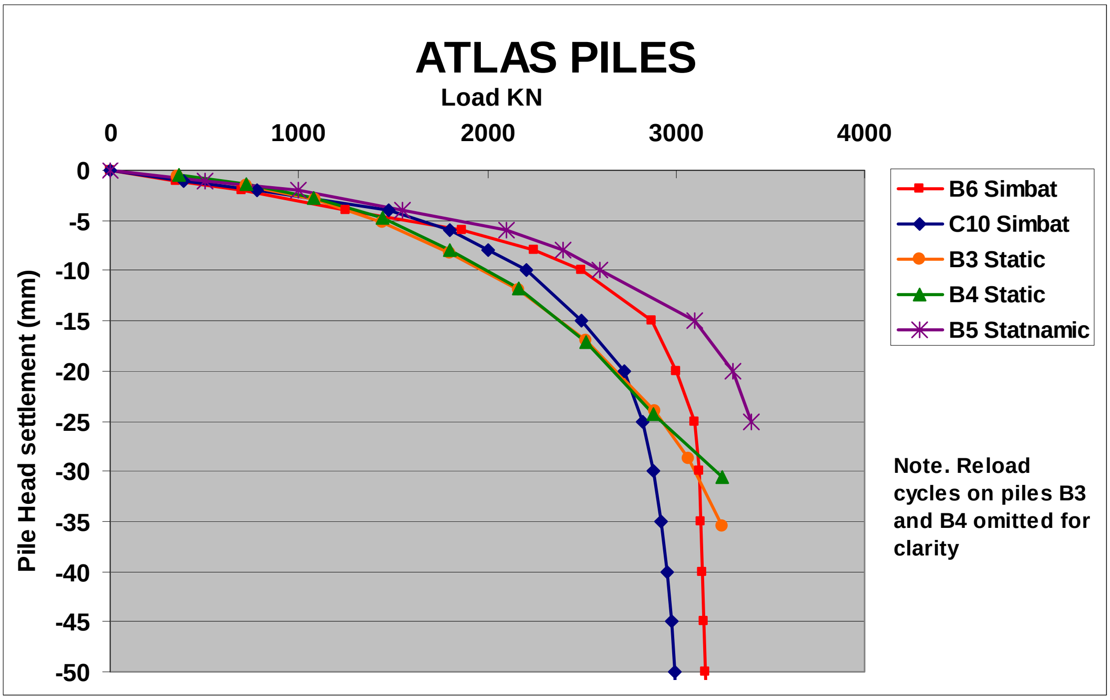

Fig 21. The two static tests show very close agreement. SIMBAT tests show a small disparity in accordance with “driving” plots.

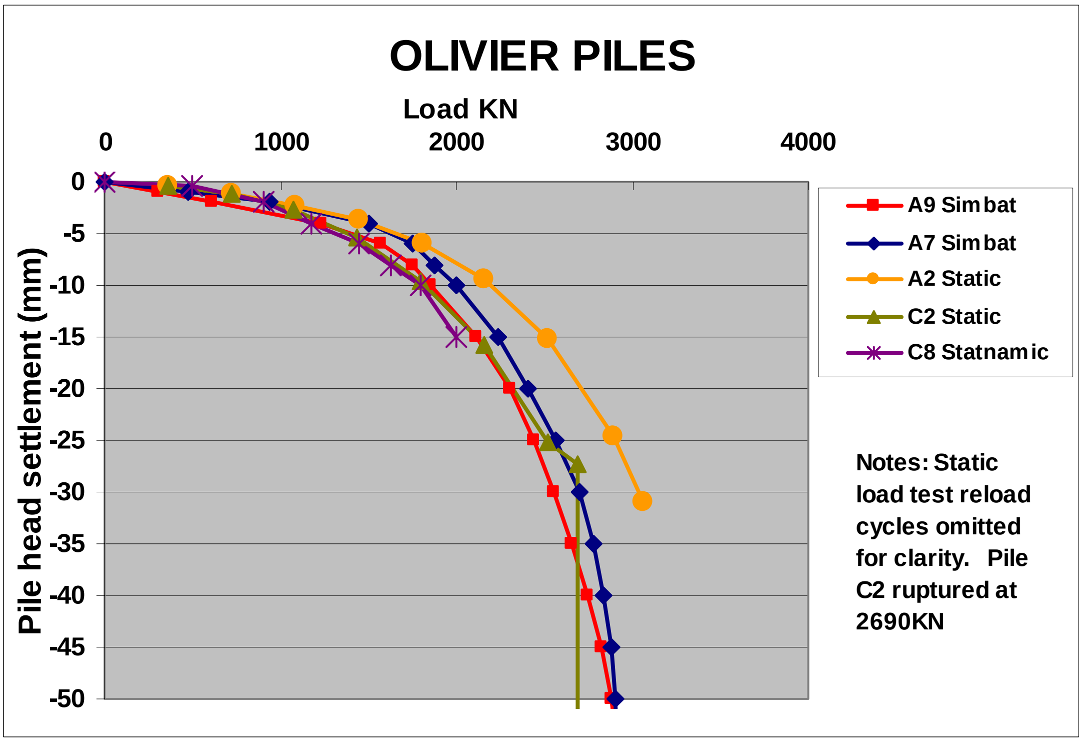

Fig 22. All test results in close agreement, particularly the two SIMBAT and Statnamic

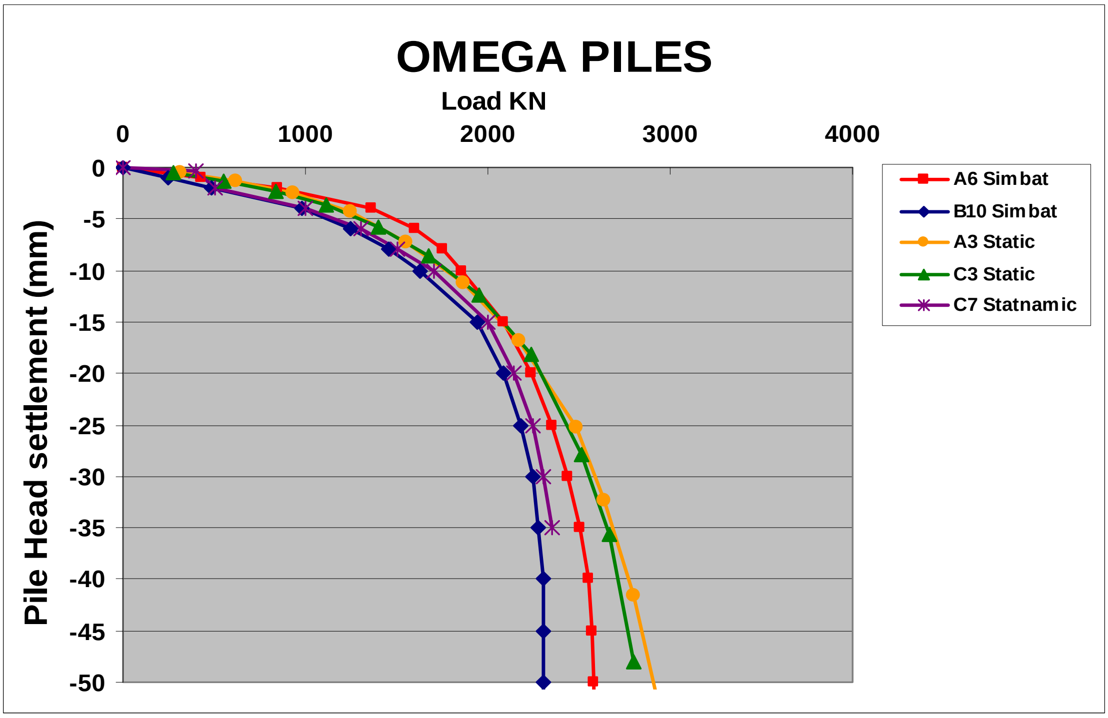

Fig 23. A remarkable set of results bearing in mind that three different methods were used on five different piles. All test results are in very close agreement with each other

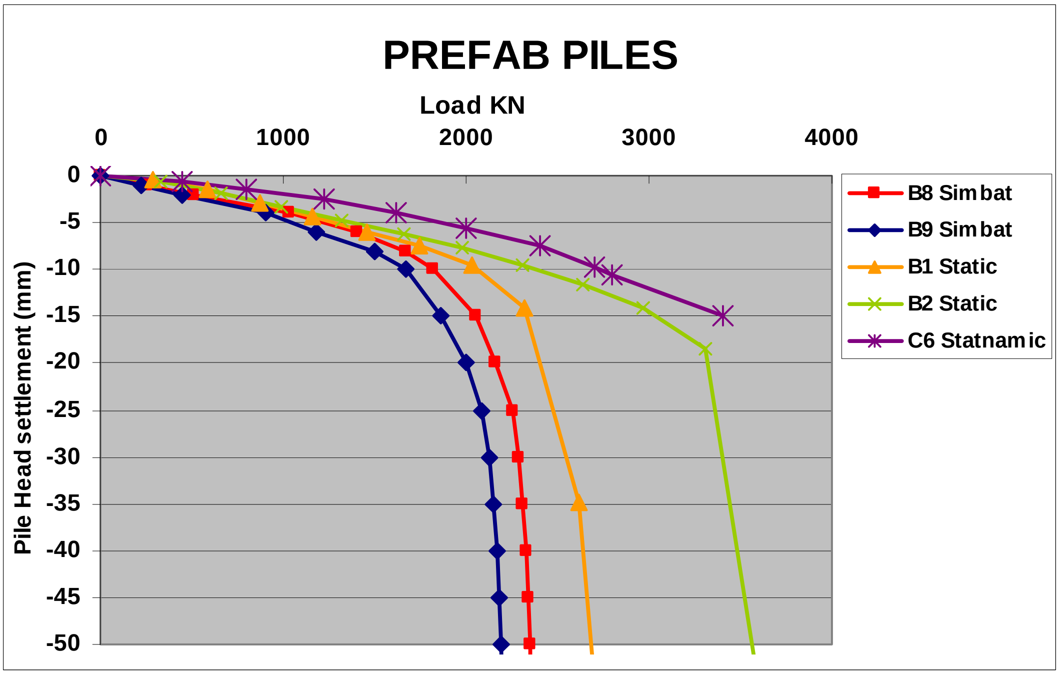

Fig 24. There is a significant disparity between the two static test results.

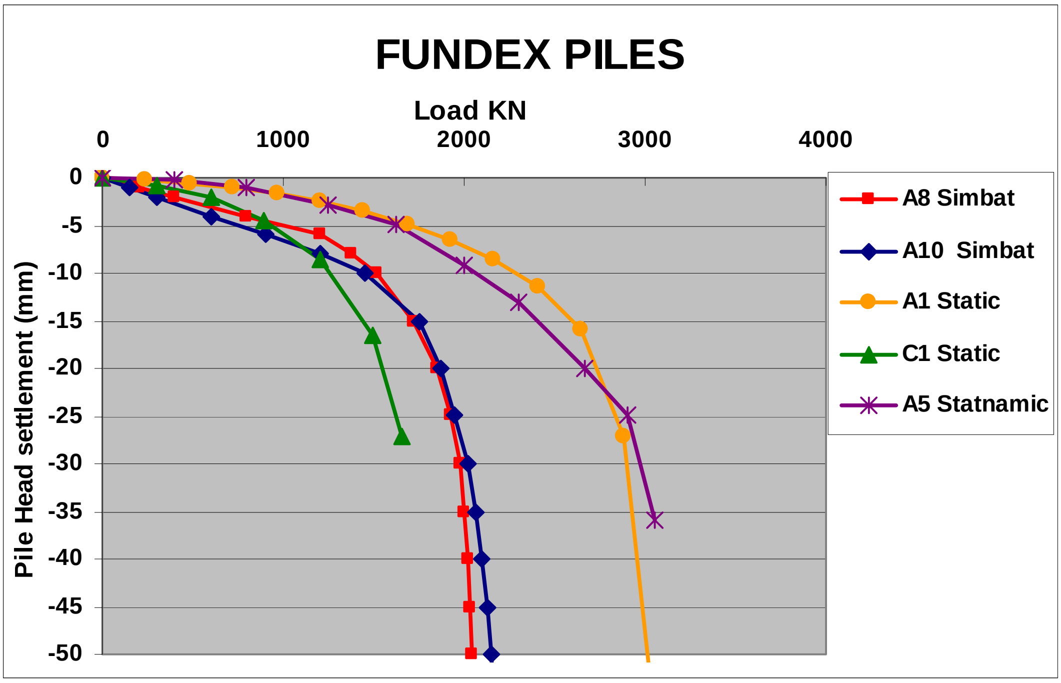

Fig 25. The two SIMBAT results in very close agreement with each other. Large disparity in static test results. On extraction, pile C1 was shown to contain dry and segregated concrete at the base.

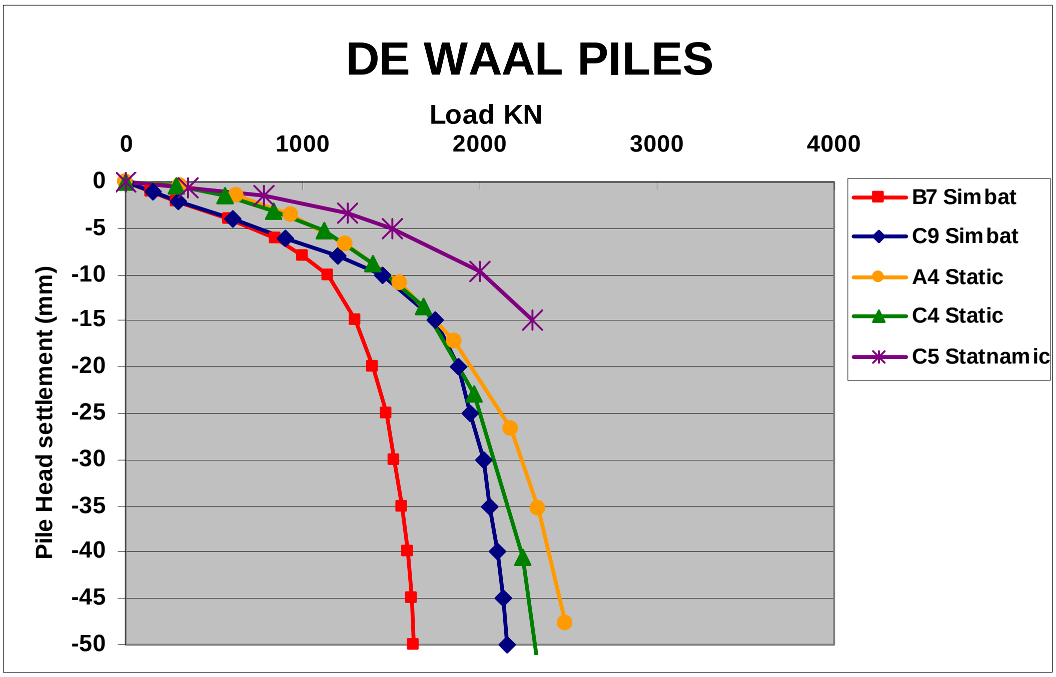

Fig 26. Significant differences between SIMBAT, Static and Statnamic results.

CONCLUSIONS

- **This paper has drawn attention to certain aspects of the SIMBAT test which may be responsible for or at least have contributed towards obtaining the "best" predictions on the Limelette site.**

- **On three pile types, (out of six) the Atlas, Olivier and Omega, there was a high level of agreement between the static, SIMBAT and Statnamic test results. On the Omega piles in particular, the agreement was remarkable, bearing in mind that this was three different test methods on five different piles.**

- **On the other three pile types, Prefabricated, Fundex and De Waal, it is difficult to draw conclusions because of the variability in the static results. The large disparity in the Fundex pile tests were attributed to dry and segregated concrete at the base of pile C1. However, no such construction anomaly can be held responsible for the similar disparity in the Prefab static tests.**

- **The author believes that the only way to obtain true dynamic/static correlations is to test the <u>same pile</u> by different methods. One option (although expensive) would be to test a pile 4 times, static, dynamic, static, dynamic in quick succession, allowing no time for set up. In this way, the middle dynamic test would be sandwiched between two static test and the middle static would be sandwiched between two dynamic tests.**

This paper is dedicated to the memory of Dr Allen Davis who left us too soon, late last year.

Ref 1 "BELGIAN BUILDING RESEARCH INSTITUTE. 2000-2002. Soil displacement screw piles - calibration of calculation methods and automatisation of the static load test procedure : stage 2 - end-bearing piles. Research program subsidised by the Belgian Federal Ministry of Economical Affairs, convention number CC-CI-756."

Ref 2 A.HOLEYMAN and N.CHARUE. 2003. International Pile Capacity prediction event at Limelette. Proceedings of the second Symposium on Screw Piles, Brussels. Edited by J. Maertens and N.Huybrechts. Pub Balkema. Pp215 - 234

Ref 3 J.PAQUET. 1988. Checking Bearing Capacity by Dynamic Loading – Choice of a methodology. Application of Stress Wave theory to Piles, Third International Conference. Ottawa, pp 383 - 3998

Ref 4 A.HOLEYMAN, et al. 1988. Comparative dynamic pile testing in Belgium. Application of Stress Wave Theory to Piles, Third International Conference. Ottawa, Canada. Pp 542 - 554

Ref 5 C.BAKER et al. 1991. Dynamic Testing to predict Static performance of Drilled Shafts – results of FHWA research.

Ref 6 N.HUYBRECHTS and V.WHENHAM. 2003. Pile testing campaign on the Lamellate test site & Installation techniques of screw piles. Appendix A. pp 100 – 130.