

The Reliability of DLTWAVE

Introduction

Whenever Profound enters a new market with its products there are two questions that are invariably posed: what is Profound and more importantly how do you know that their testing equipment works. In this article we will address these two questions, albeit that the second question is only answered for DLTWAVE, the signal matching software used to evaluate the dynamic load results tests for foundation piles. The response regarding DLTWAVE is solely based on papers that were presented at international conferences without Profound's support or input, because we felt that this approach would be more effective than to present our own test data, and it consists of two parts. The first part is a comparison with the outcome of Static Load Tests, the traditional way of pile testing. The second part is a comparison with the only other software widely used for this purpose, CAPWAP. We trust that by presenting these data the two questions are answered conclusively and that based on these answers DLTWAVE is considered a reliable tool to analyze the results of dynamic load tests.

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Profound

Profound began in the 1960's as a group of the Building and Construction Research Department within the Dutch organization for Applied Scientific Research (TNO), the second largest R&D organization in Europe. The Foundation Pile Diagnostic Systems (FPDS) Group, as it was called, took on a broad range of activities for its clients in foundation pile testing with state-of-the-art technology that was developed in research and development projects. Their equipment and software also enabled clients to perform or monitor foundation pile testing themselves.

During the 1980's the market, and especially the international market, expanded substantially for these activities. To ensure continued optimal services to all clients (incl. the international clients) while maintaining the high technology standards of the products, the decision was made in 1999 to change the department to a fully owned subsidiary of TNO. This subsidiary was called Profound (**PRO**fessional **FOUN**dation **DI**agnostics), which was split off from the TNO organization some four years later, when it became a privately held company in 2002.

In 2004 Profound signed an agreement with Verbeek Management Services in Tyler, TX to establish a local base for Profound's North American operations. As part of their Management Consultancy Services, VMS assists U.S. companies with their operations in Europe and European companies with their business in the U.S., and to represent Profound in North America a new company "VMS-Profound" was established.

TNOWAVE and DLTWAVE

Although it is a small country, The Netherlands has a huge piling market because of the poor soil conditions. Every year between 700,000 and 1,000,000 pre-cast piles are driven and a similar number of cast in situ piles are installed. It is therefore not surprising that there was a need for basic research in the area of pile foundations. Consequently in the 1960's a group was established within the Building and Construction Research Department of the Dutch organization for Applied Scientific Research (TNO), the second largest R&D organization in Europe.

In the 1970's this group started to really focus on the field of stress wave applications when two Dutch companies (Heerema and HBG) together with TNO intensified their research in this area because of the offshore pile driving activities associated with the development of the North Sea oil fields.

In 1975 Heerema performed research at the TNO laboratories to investigate soil behavior during pile driving to develop models for pile driveability analysis, elaborating on the work done by H.M. Coyle and G.C. Gibson in the United States. At the same time HBG used the stress-wave application in their development of the Hydroblok, which led to the release of PILEWAVE in 1974.

Following the release of PILEWAVE, TNO wanted to develop its own wave equation program. While it was considered to use Smith's algorithm as the basis for such a program, it was decided to use the method of characteristics instead and the first issue of the program TNOWAVE was released in 1978. In the following years much work was done to better understand the dynamic soil model parameters, and to establish signal matching techniques, similar to CAPWAPC. The first commercial version of the DLTWAVE module was released in 1982 and since then the program has been upgraded several times to make full use of the technological developments as they became commercially available.

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DLTWAVE vs. Static Load Testing

As soon as DLTWAVE was released questions were asked how the interpretation of Dynamic Load Testing (DLT) with DLTWAVE compared with the results of the traditional way of pile testing, i.e. Static Load Testing (SLT). And whenever Profound enters a new market this very question invariably is raised.

In 2000 Goldemberg et al. addressed this question in a paper presented at the GeoEng conference in Melbourne, Australia, based on their experience with the early use of this method in Argentina. The objective of the paper was to present correlations between Dynamic and Static Load Tests performed on the same pile, including all the information that the Geotechnical Consultant had at the moment of analyzing the test results and highlighting how he arrived at those conclusions. The SLT were performed in accordance with the applicable ASTM standard (ASTM 1143), while the DLT was analyzed with DLTWAVE.

The paper first describes tests from three different projects:

- a building project in Buenos Aires with a total of 408 concrete cast-in-situ piles, that could be split into three types (based on the pile diameter). Of each group 9 or 10 piles were subjected to DLT and one of these piles was then tested a second time using SLT (see table 1).
- an industrial facility in Buenos Aires with a total of 250 pre-cast concrete piles. Of these piles 20 were subjected to DLT and one of these piles was then tested a second time using SLT (14 days after the DLT). Given the discrepancy between the results, the piles were then subjected to a second DLT (5 days after the SLT) (see Table 2).
- a bridge in the Santa Fe province with 9 cast-in-situ piles. One of these piles was subjected to DLT and then tested a second time using SLT (see Table 3).

The paper then makes the following conclusion: “At it is clearly presented, the Dynamic Load Test can have an accurate static correlation, inclusive for high loads- 7MN as in this case. (...) it is an irrevocable condition - in order to obtain a good match or correlation between dynamic and static measurements of a same phenomenon pile-soil interaction - to have an exhaustive geotechnical investigation, knowledge of the parameters of the materials used for the construction on the foundation and the pile shape. Although some skepticism, that still over flies on some Engineer’s minds, Dynamic Load Testing is reliable if the above conditions are fulfilled, inclusive for high loads in cast in-situ piles”.

A similar conclusion was reached by Tchepak in a paper he presented in 1992 at the Fourth International Conference on the Application of Stress-wave Theory to Piles in The Hague, The Netherlands. An interesting part of this paper, based on the experience with DLT as it was introduced in Australia in the late 1980’s, are the author’s conclusions regarding the interpretation of DLT for different types of concrete piles:

- for enlarged base Franki piles he states: “Whilst a direct comparison of the predicted performance of the pile indicates some discrepancy between the static and the dynamic load test results, they were pleasing nonetheless to the operators, given the difficulties associated with analysis of the pile type. The (...) trend is typical of experience to date, with the comparative results of static and dynamic pile load testing showing the dynamic prediction to consistently overestimate the settlement of the pile type as compared to that obtained during static testing”.

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- for Atlas screw piles he notes: “Although Atlas piles have been successfully tested by dynamic methods (...), successful testing and signal matching was regarded as quite a challenge. The TNOWAVE analysis admittedly proved difficult. However, the results were gratifying, with the predicted load-settlement performance showing good agreement with the static loading results”.
- For pre-cast concrete piles he states: “Satisfactory signal matches were obtained and the resultant prediction of the load-settlement performance fortuitously accurate”...

A third paper we would like to mention is a paper by Van Niekerk et.al. entitled “Dynamic and Static Loading Tests for Bridges in Surinam”, which was presented during the Annual DFI Conference in 2000. This paper covers the test results for open ended steel piles that were used for the construction of two bridges in Surinam in South America. In this paper the authors note that “the difference between the results of the dynamic and static tests appear to depend on the soil stratification, the relative resistance of the layers and the wall thickness of the pile. The difference is approximately 20 %, the dynamic tests showing the higher results. In addition the dynamic and static bearing mode has to be considered and verified by the static test mode. Because the dynamic test results are consistent and verified by the static test mode, it is possible to have fewer, more expensive static tests.”

These papers mentioned above, which were presented at international conferences without Profound’s support or input, support our internal research and testing, and demonstrate that Profound’s DLTWAVE program provides accurate results, irrespective of the pile type. Obviously the quality of the predictions made with the DLTWAVE program depends to a large extent on the competence of the operator. Signal matching techniques do not produce unique solutions, and therefore it is essential that signal matching is always done by experienced staff, irrespective of the type of program used.

Finally, it should be remembered that DLTWAVE is part of a suite of programs called TNOWAVE, thereby clearly linking these programs to the Dutch governmental research organization TNO. This link, which is continuing even though the Profound organization was split off from the TNO organization some four years ago, is in and of itself a clear demonstration of the confidence in and the quality of the product.

DLTWAVE vs. CAPWAPC

Whenever Profound enters a market where the CAPWAP program is already used, there is another question that is frequently asked: how does DLTWAVE compare with CAPWAP.

In a paper presented in 1994 at the 5th International DFI Conference and Exhibition on Piling and Foundations in Belgium, Kawabata et. al. discuss their experience with 3 steel piles with a diameter of 400 mm that were subjected to both a SLT and two DLTs, whereby the test results were analyzed by one engineer using DLTWAVE and another engineer using CAPWAP (see Table 5). The author concludes that both matching analyses could estimate the load-settlement relationship, although the two systems produce different predictions. This is important to remember: as mentioned above, signal matching does not produce a unique solution to begin with, and therefore it very well possible that test data are interpreted differently by different operators, even when they use the same system. It is therefore no surprise at all that the testing arrangement as

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described by Kawabata (different systems with different operators) produced different predictions.

A second relevant paper in this regard is the paper by Tchepak mentioned earlier. Apart from the information already summarized Tchepak also describes a test whereby a pile had been driven and tested by others using the CAPWAP program. Some 12 months later he was asked to test the same pile using the DLTWAVE program. While the calculated load bearing capacities differed substantially (accounting for the set up effects over the 12 months period), both programs confirmed the same soil damping coefficient J.

These two papers are typical of the feedback we have received in recent years: both programs can provide accurate results. While there are distinctive differences between the two programs (e.g. the soil model in DLTWAVE is more sophisticated) it would be presumptuous to claim that only one program can be used for the analysis of DLT in order to obtain accurate results. And once again, the quality of the predictions made with either program depends to a large extent on the competence of the operator.

Conclusion

In this article we have tried to provide an objective assessment of the capabilities of the DLTWAVE program. To achieve this we have used papers presented at international conferences without Profound's support or input that relate to the comparison between Static Load Testing and Dynamic Load Testing using DLTWAVE for data analysis as well as between DLTWAVE and CAPWAP. Obviously we can support the conclusions by the various authors with our own internal research and testing (the results of which are available upon request), but we hope that these Third Party assessments we have demonstrated that DLTWAVE is a reliable tool to analyze the results of dynamic load tests.

References

Goldemberg, H., Goldemberg, J.J., 2000, *Correlation between DLT and SLT – Case Histories*, Proceedings of the GeoEng conference, Melbourne.

Tchepak, S., 1992 *Dynamic and Sonic Pile Integrity Testing – A Contractor's Experience*, Proceedings of the Fourth International Conference on the Application of Stress-wave Theory to Piles, The Hague, The Netherlands.

Niekerk, W.J. van, Ramler, J.P.G., Kort, P. de, 2000, *Dynamic and Static Loading Tests for Bridges in Surinam*, Proceedings of the Annual DFI Conference, New York.

Kawabata, N., Hayashi, M., Wakiya, Y., Kobayashi, Y., Nishimura, S., 1994, *Simultaneous Loading Tests of Steel Piles by Dynamic and Static Methods*, Proceedings of the 5th International DFI Conference and Exhibition on Piling and Foundations, Belgium.

Note: these papers can be found on Profound's website: www.profound.nl or www.profound-usa.com.

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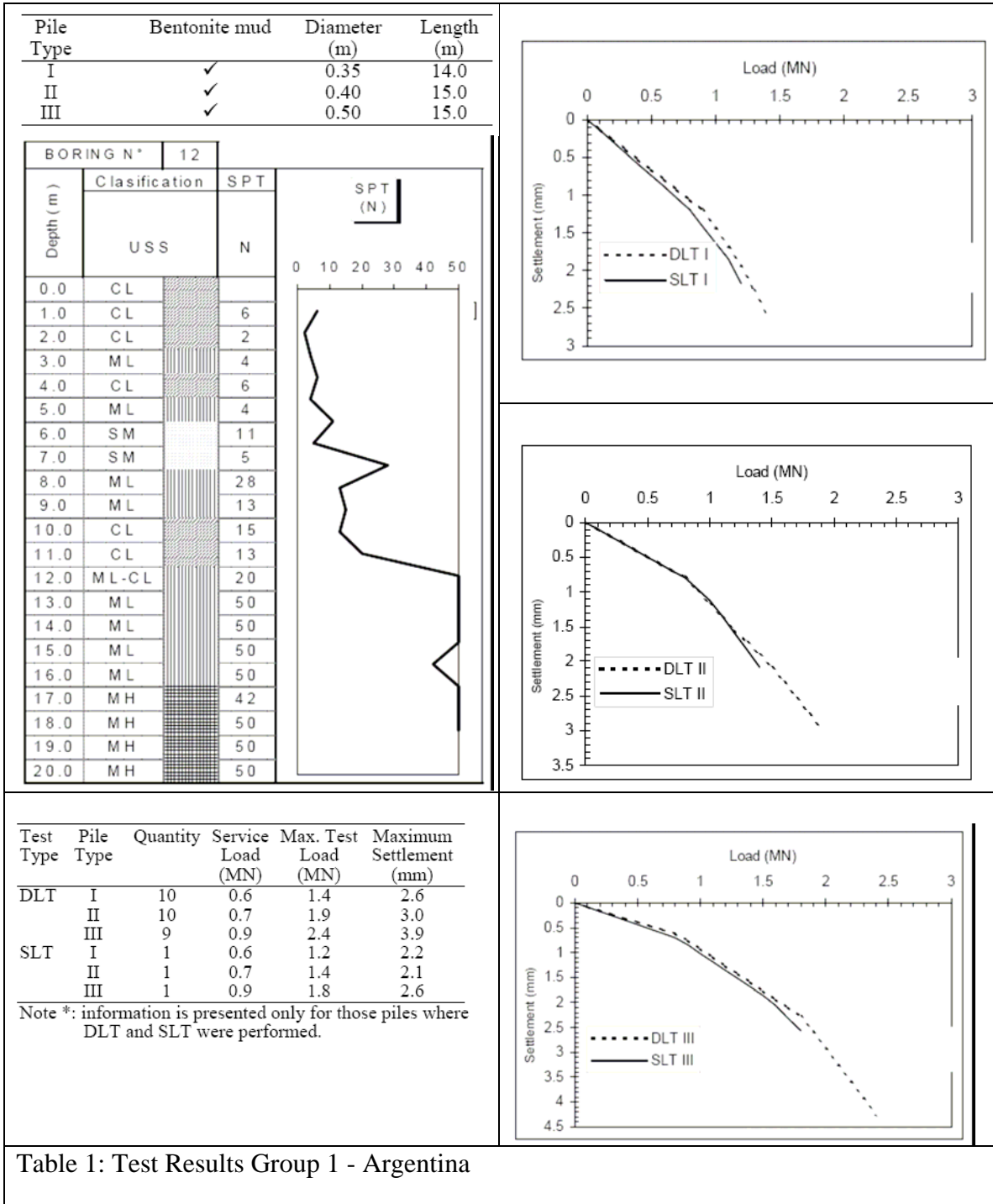


Table 1: Test Results Group 1 - Argentina

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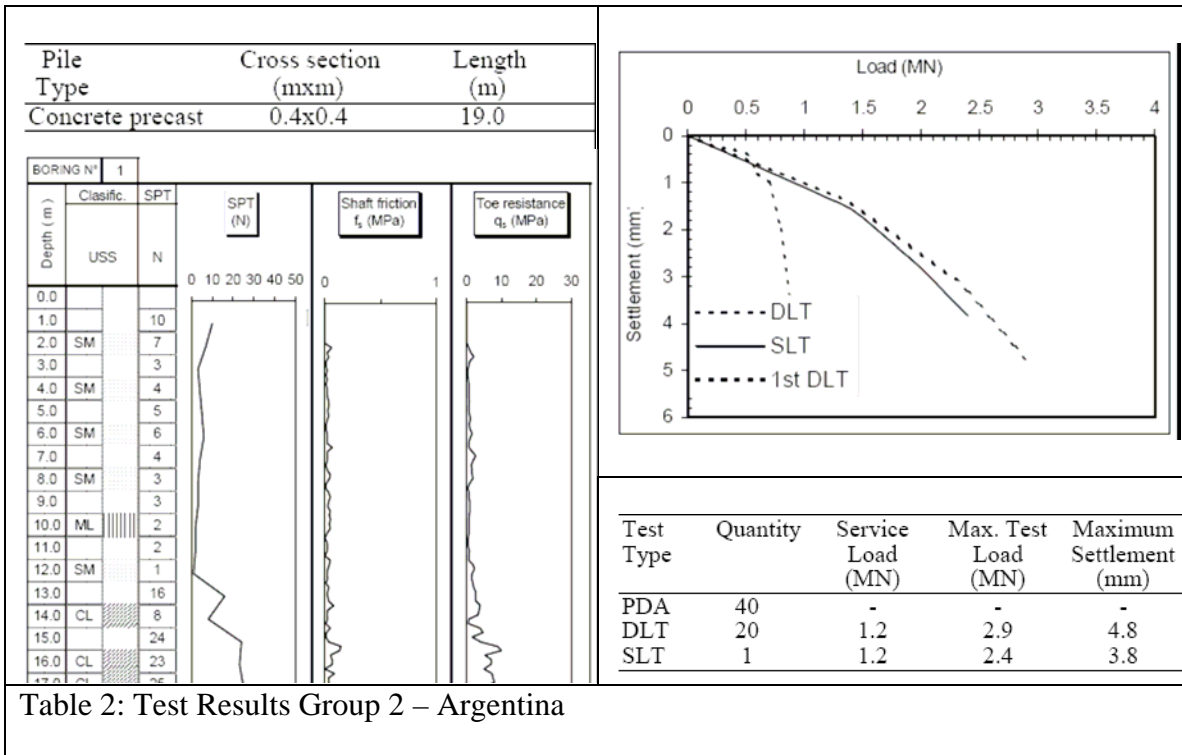


Table 2: Test Results Group 2 – Argentina

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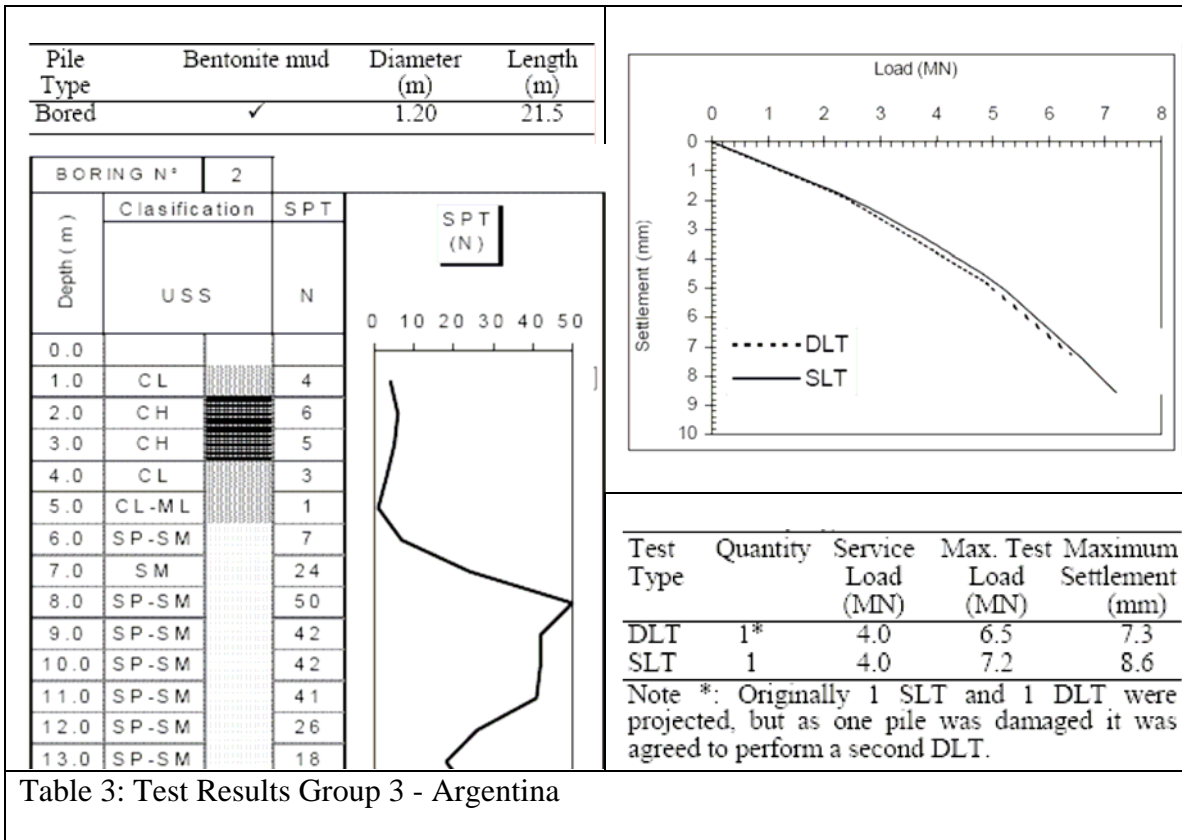
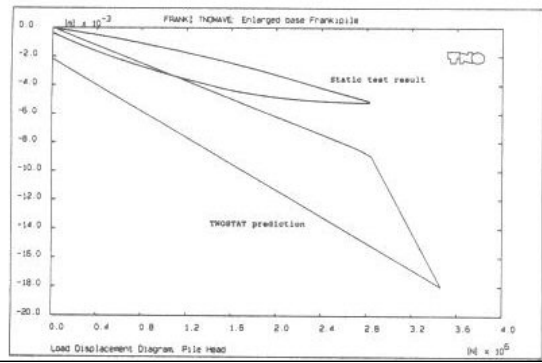
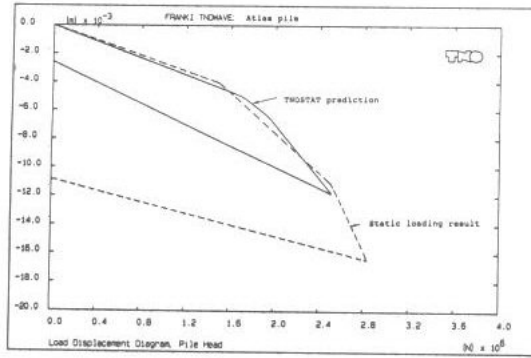


Table 3: Test Results Group 3 - Argentina

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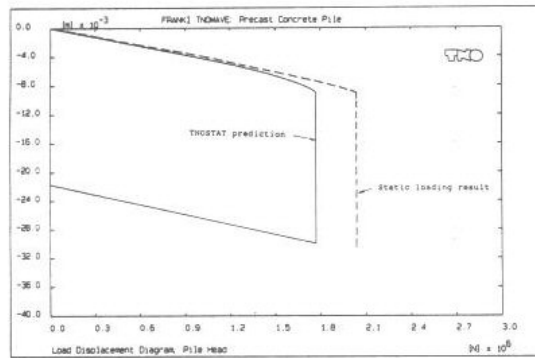


Prediction for enlarged base Franki pile



Prediction for Atlas screw pile

Table 4: Test Results - Australia



Prediction for pre-cast concrete pile

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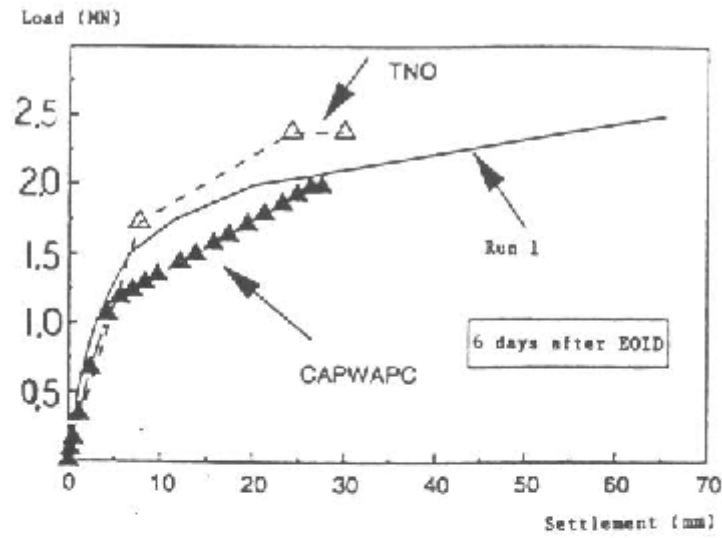


Fig 11 Comparison of Dynamic and Static Loading Test

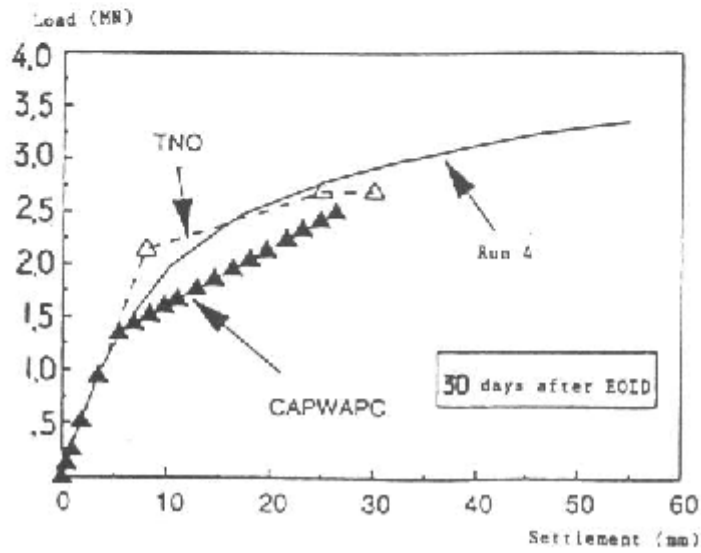


Table 5: Test Results - Japan