

COMPARISON OF STATNAMIC LOAD TEST AND STATIC LOAD TESTS AT THE ROTTERDAM HARBOUR

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An extensive pile test program has been conducted on precast concrete piles and steel piles at the Rotterdam Harbour. The goal of the research project was to prove that higher limit values for toe and shaft resistance could be applied than prescribed in a new Dutch code. An additional goal was the comparison of static and dynamic piles tests. Static load tests (SLT), Statnamic load tests (STN) and dynamic load tests (DLT) have been performed. Soil investigation data and pile design will be discussed. The paper extensively describes the comparison between load-settlement behaviour for STN and SLT .

1. INTRODUCTION

Many kilometres of quay wall being constructed as part of the extension of the harbours of the Maasvlakte near Rotterdam. For the foundation of these quays, a considerable amount of foundation piles are needed. Pile design in The Netherlands is based mainly on soil investigation by CPT (the cone resistance in Dutch Cone Penetration Test). Static load testing is rarely performed.

The geotechnical design code in The Netherlands (NEN 6743) contains design norms for pile foundations. These norms are based on linear relationships between pile toe resistance and as well as between shaft friction and CPT values. Limit values for shaft friction and toe resistance are prescribed. Because of the high CPT values, which are measured in the Pleistocene sands at the Maasvlakte area, considerable foundation construction costs would be saved if higher limit values were to be applied.

For this reason a pile testing project was organised by Public Works Rotterdam in co-operation with a steel pile supplier (ODS/ARBED), the foundation of precast concrete pile suppliers (PREPAL), a consultancy company (MOS), the piling contractor (HBW), the pile testing companies (IFCO, Fundex) and a research organisation (TNO).

The testing was performed on 3 steel piles and 3 precast concrete piles. The piles were instrumentated with strain transducers along the shaft.

One of the additional goals of the testing program was the comparison between static load test (SLT) results and dynamic pile testing methods. The paper will deal with the comparison of SLT and STN testing. The comparison of STN with other dynamic methods will be published elsewhere. Not all test results were available yet the time of publication of this paper. For this reason, results of instrumented piles with strain transducers along the shaft will be published at a later stage.

2. SOIL INVESTIGATION DATA

An extensive soil investigation comprising Cone Penetration Tests (CPT), drilling and laboratory testing was carried out. Figure 1 gives a typical result of a Dutch cone penetration test, performed at the test site.

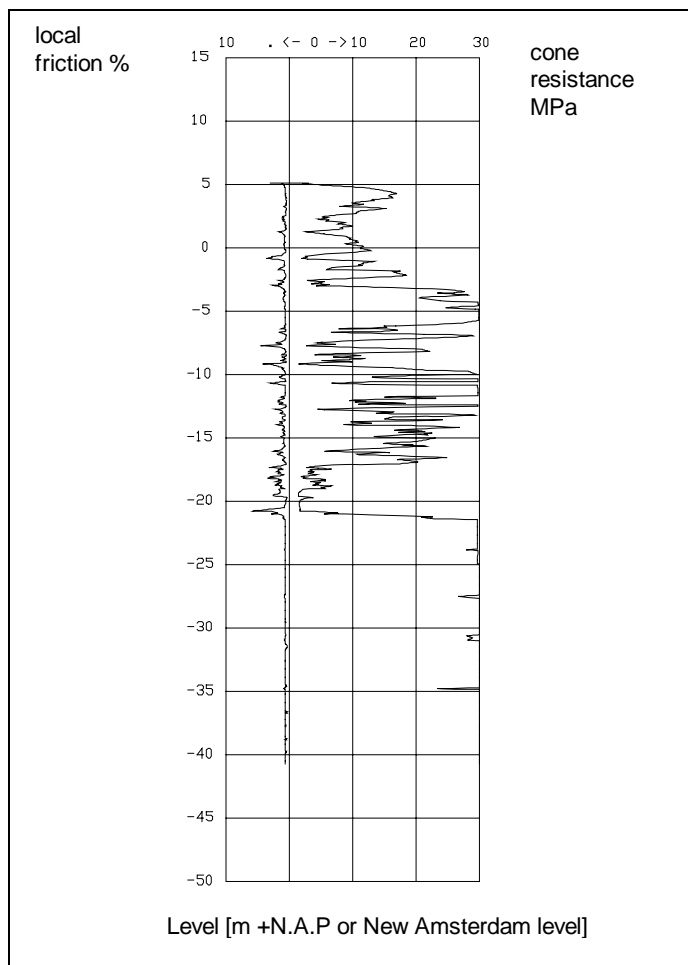


Figure 1: Example CPT result (DN 222)

Between NAP +5m and NAP -18m, there are clayey and silty sand layers. Between NAP -18 m and -21m, there is a cohesive layer consisting of clay and peat, underneath which there is a very dense pleistocene sand layer.

The toes of most foundation piles in this area are located in the very dense sand layer below NAP -21 m.

In most cases, the shaft friction in the top sand layers gives an extra load on the pile (negative shaft friction), because the cohesive layer between NAP -18m and -21m, is subject to subsidence.

3. PILE CONSTRUCTION AND INSTRUMENTATION

The test piles have all been driven to a level of about NAP -25 m. To prevent the occurrence of shaft friction in the upper part of the pile during the tests, the precast concrete piles were driven inside an open steel pile, after the soil inside this steel pile had been removed to a level of NAP -18m. This was not considered necessary for the steel test piles because the toe of the steel test piles was enlarged, which causes the shaft friction in the upper part of these piles to be relatively small.

To be able to establish the contribution of both shaft friction and toe resistance in the total bearing capacity, the pile is equipped with strain transducers at various levels.

Data of the test piles is given in table 1. Figure 2 shows the installed test piles.

Pile no	Cross section mm ²	Length m	Type	Remarks	
1	HP 320x147	31.00	steel ARBED	enlarged toe	no toe plate
2	HP 320x147	31.00	steel ARBED	enlarged toe	with toe plate
3	HP 320x147	31.00	steel ARBED	enlarged toe	with toe plate
6	380 x 380	30.58	precast concrete		
8	380 x 380	30.26	precast concrete		
10	380 x 380	30.66	precast concrete		

Table 1. Pile data

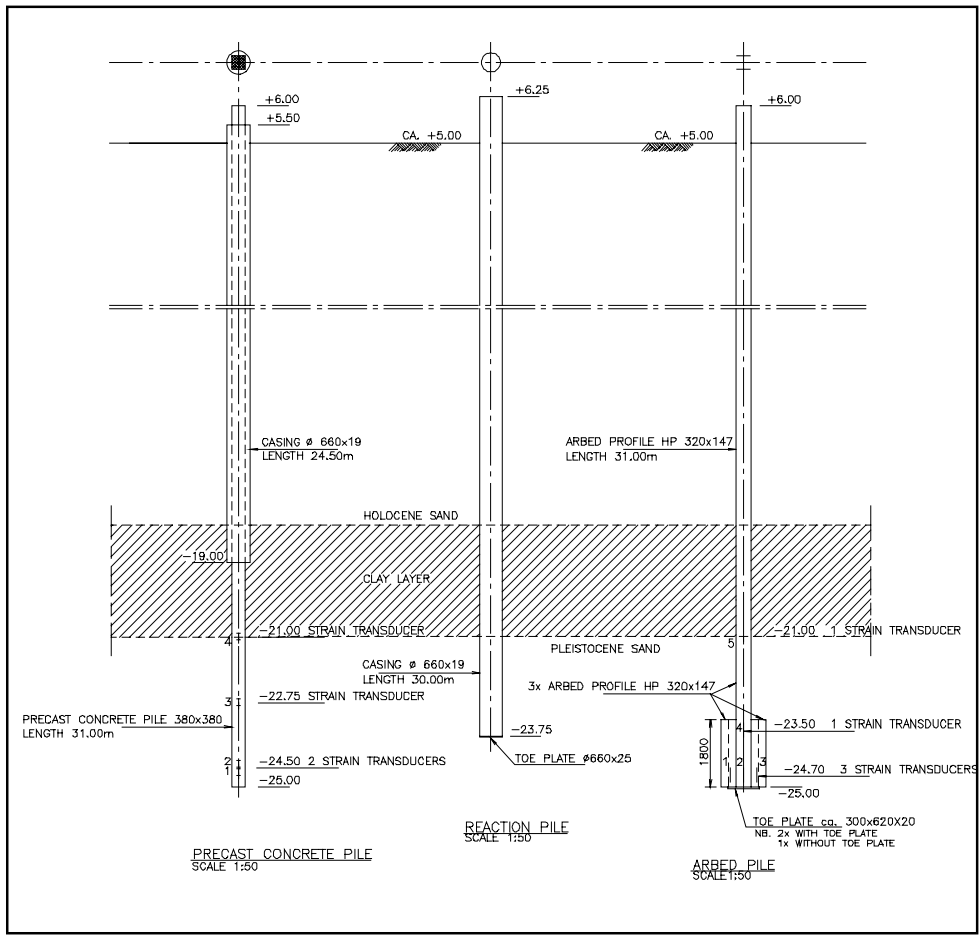


Figure 2, Test piles

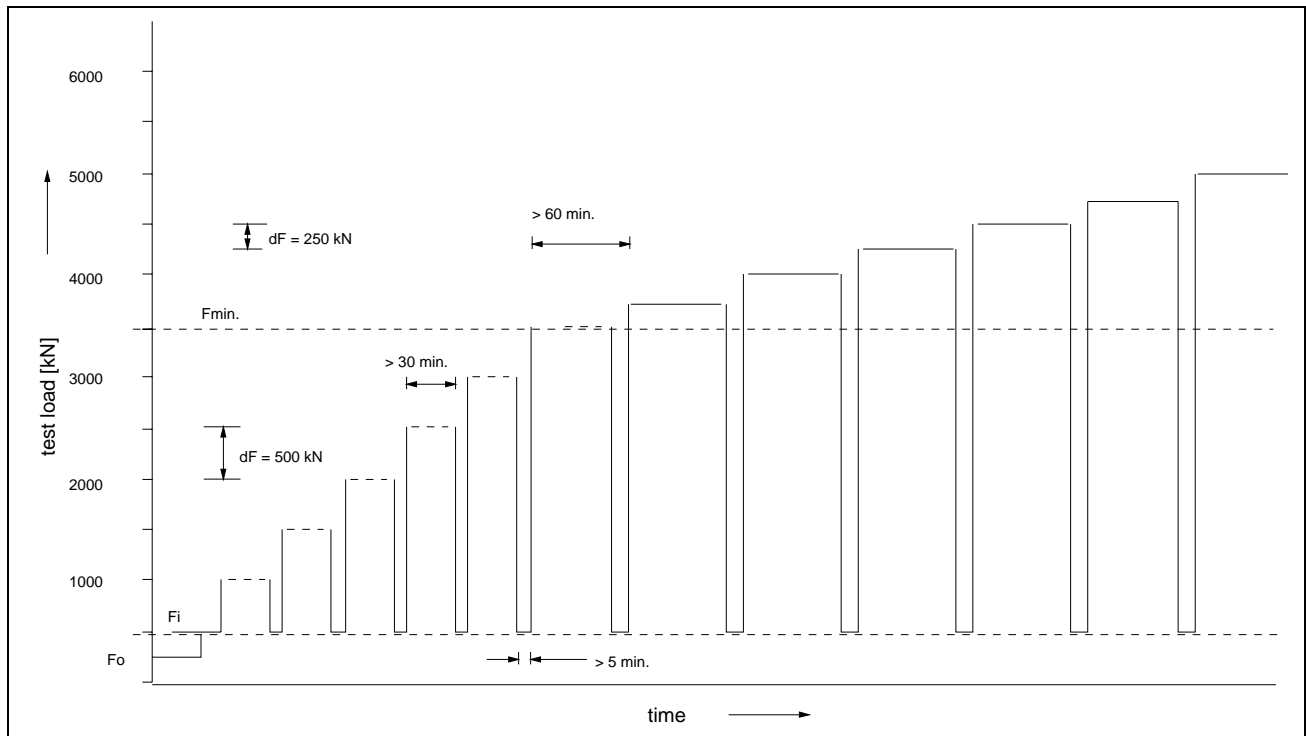
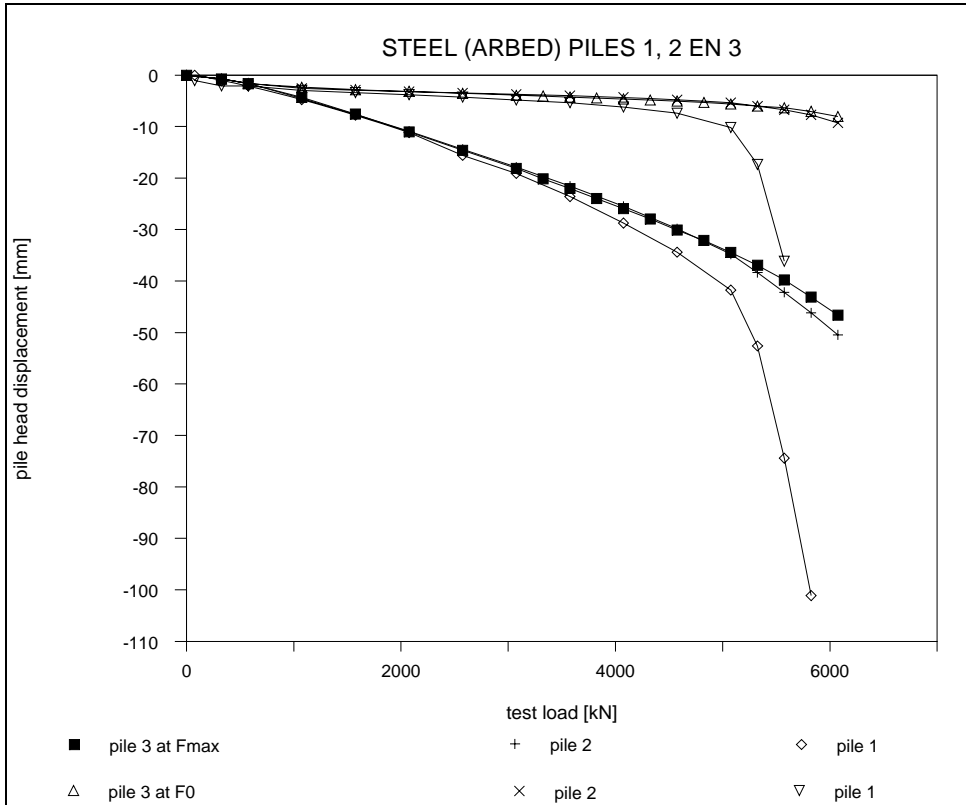


Figure 3, Load step diagram

4. STATIC LOAD TEST



The piles have been subjected to consequent load steps as shown in figure 5. In figure 6 the resulting load-displacement diagram for the steel piles are shown.

Figure 4, Resulting load-displacement diagrams of steel piles

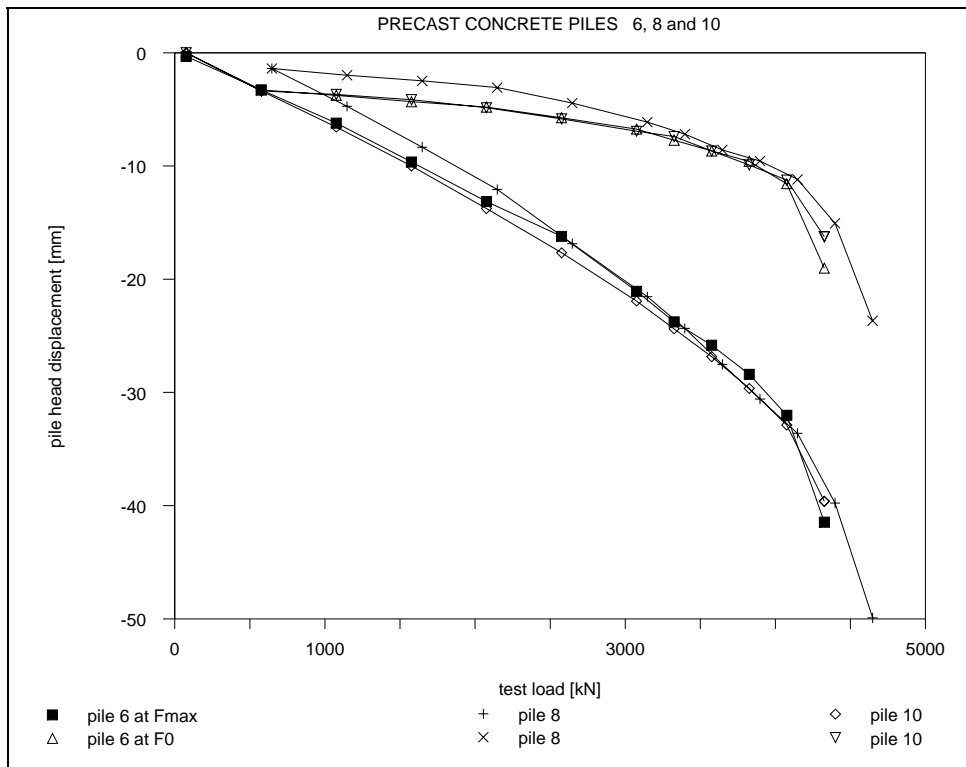


Figure 7: Resulting load-displacement diagrams of concrete piles

5. STATNAMIC LOAD TEST RESULTS

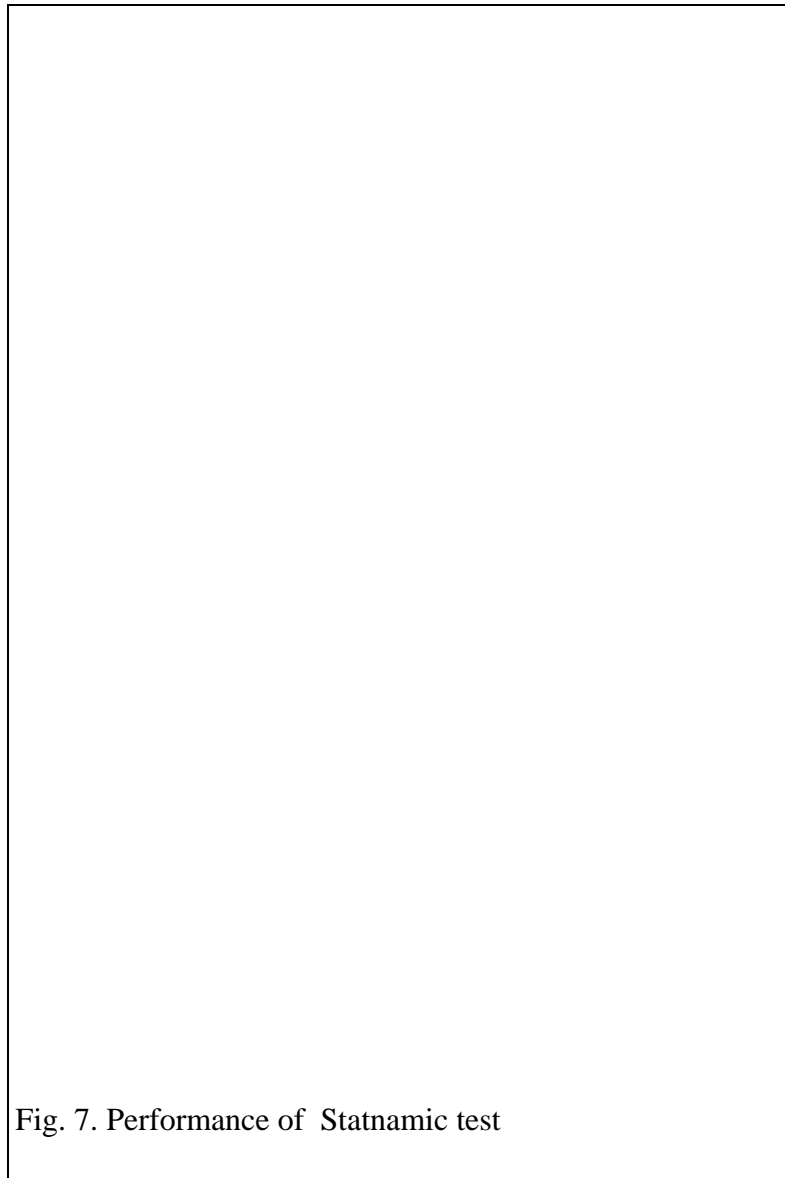


Fig. 7. Performance of Statnamic test

After the SLT tests the STN tests were performed by TNO with a 8 MN loading device. The applied amount of reaction mass was 37500 kg for the steel ARBED piles. The reaction mass for the concrete precast piles varied between 28000 kg and 30600 kg. Figure 7 represents the STN testing on one of the piles.

During the STN test, the pile head load and displacement have been measured with the TNO Foundation Pile Diagnostic System (FPDS-3). Measured signals are presented in Fig. 8 and Fig. 9 From the measured signals STN load-displacement diagrams are drawn

The STN results have been analysed according to the Unloading Point Method (UPM) (Middendorp, 1992). With this method, the static resistance at maximum displacement is calculated first and secondly the damping force is derived. Damping force and inertia force are eliminated from the STN measurements and as a result a hyperbolic load-displacement curve is obtained, predicting the static load behaviour of the pile.

Reported predictions of static load-displacement are presented in Figure 11. Although the STN test was performed after the static load test, the load-displacement behaviour of the piles was not known to TNO at the time of reporting. Information was available about the maximum capacities reached, but not the corresponding settlements.

The duration (T) of the STN load for all tests was approximately 0.1 s. Stress wave numbers N_w (Middendorp, 1995) can be applied for the control on stress wave phenomena. The stress wave number is defined as the wavelength divided by the pile length ($N_w = c.T/L$). As a rule of thumb for wave number values $N_w > 12$ stress wave phenomena can be neglected. The wave number values for the concrete piles are $N_w = 13$ ($c = 4000$ m/s) and just satisfy the condition. The steel piles have stress wave number values $N_w = 16$ ($c = 5100$ m/s).

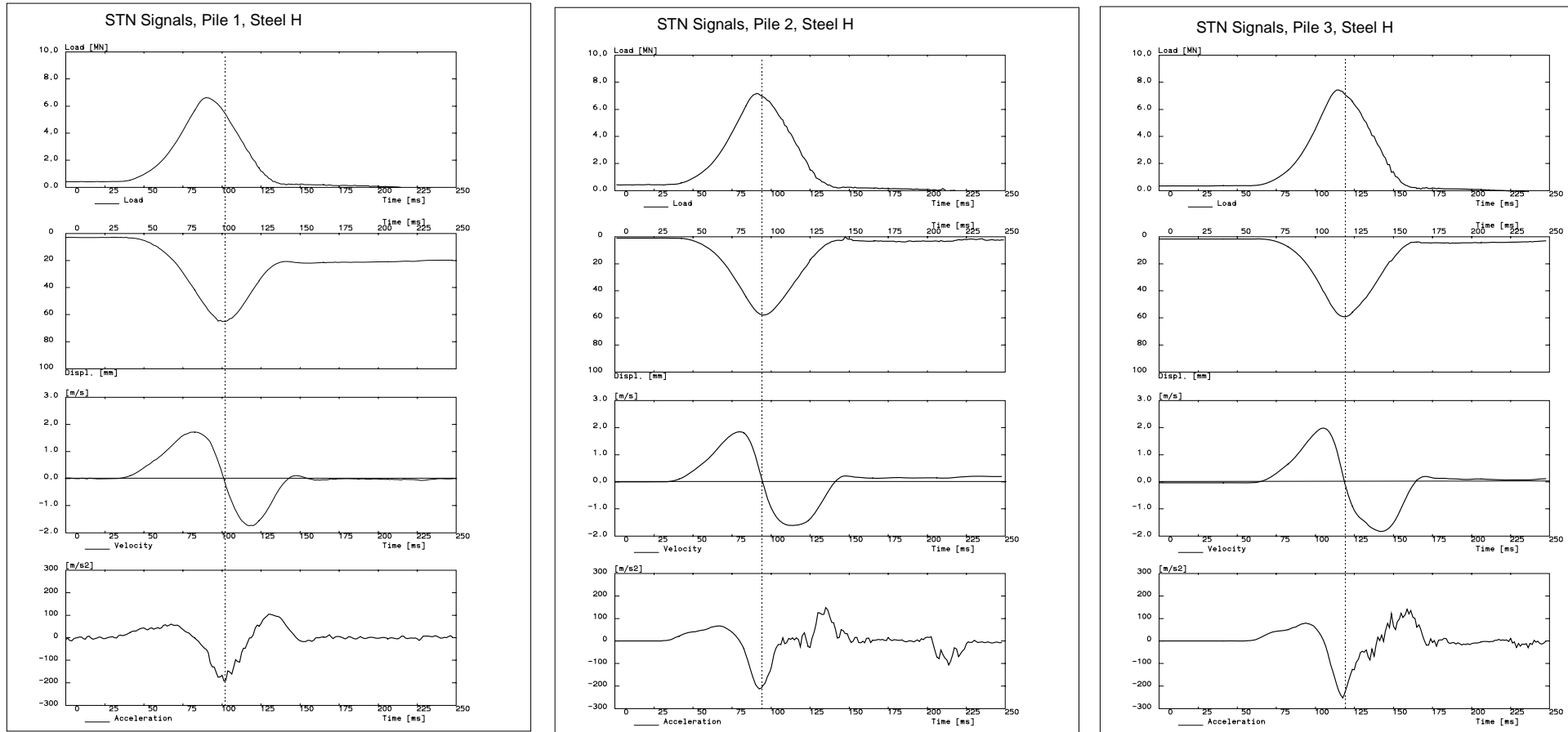


Figure 8. STN signals of the steel piles

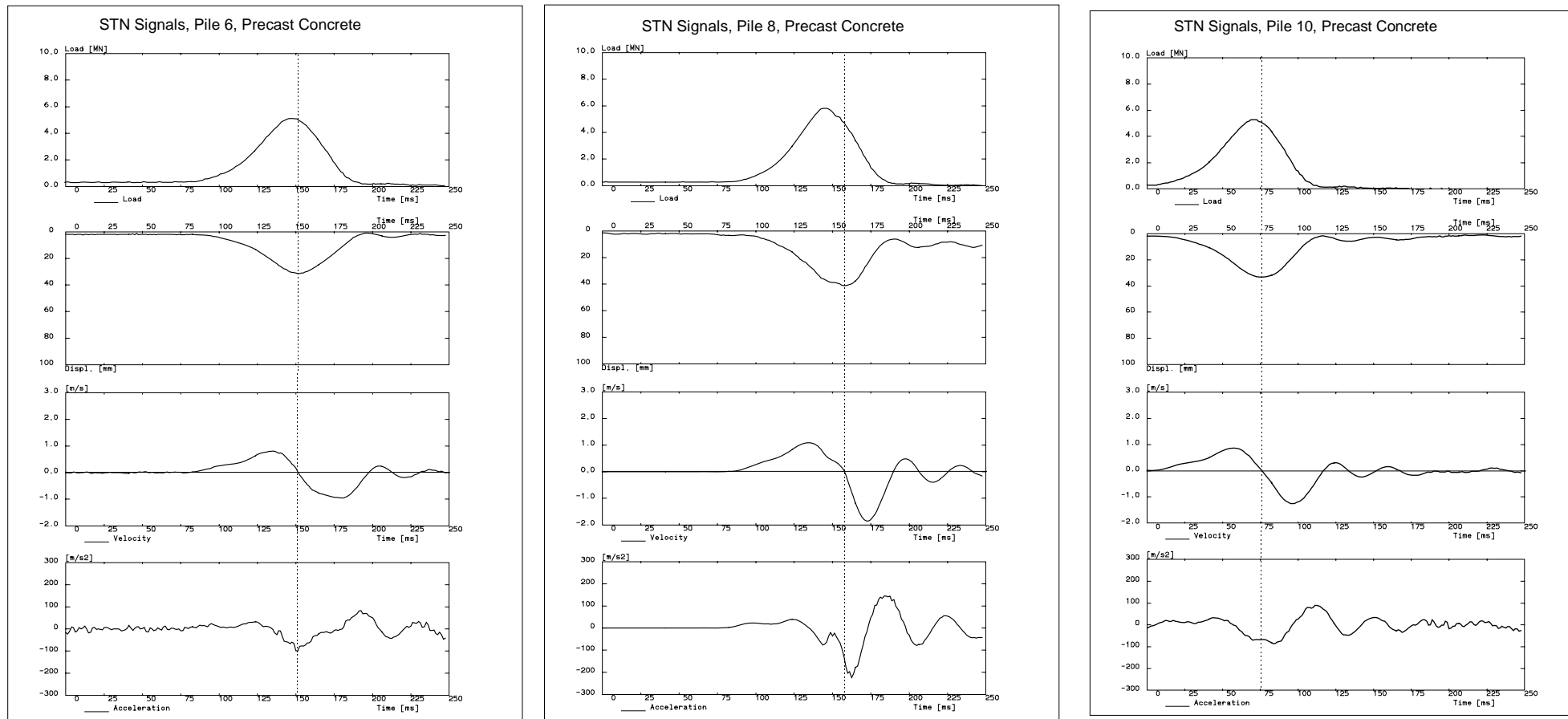


Figure 9. STN signals of the concrete piles

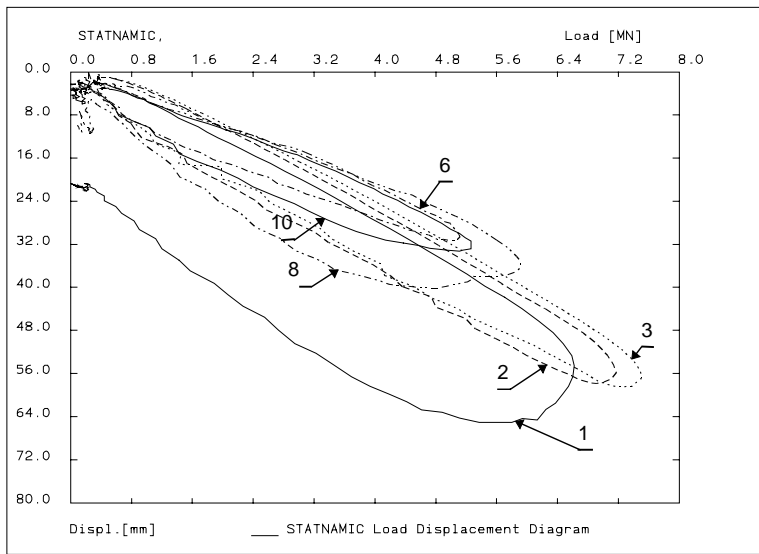


Fig 10. Overview of STN Load-displacement diagrams

In Figure 10. the STN load-displacement diagrams have been presented for all tested piles.

It can be seen that the steel piles 1,2 and 3 have been loaded to higher values than the concrete piles 6, 8 and 10. Pile 1 shows a clear permanent set while the other piles unload almost elastically.

The larger permanent set of pile 1 compared to piles 2 and 3 corresponds with the lack of a toe base plate.

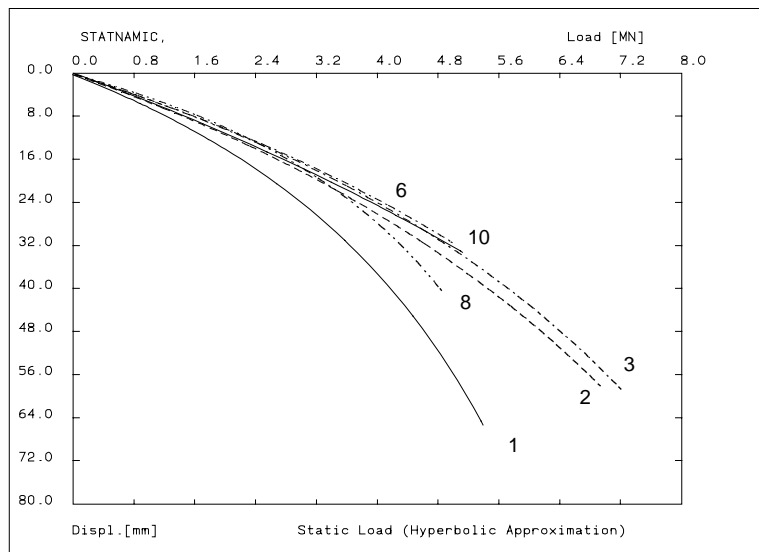


Fig 11. Overview of predicted load-displacement diagrams

In Figure 11 an overview is presented of the predicted load-displacement diagrams of all piles with the UPM method.

The piles 2, 3, 6, 8 and 10 show a similar stiffness up to 3.2 MN. After 3.2 MN, deviations occur.

Pile 1 shows a less stiffer behaviour than the other piles and has the lowest capacity of the three steel piles.

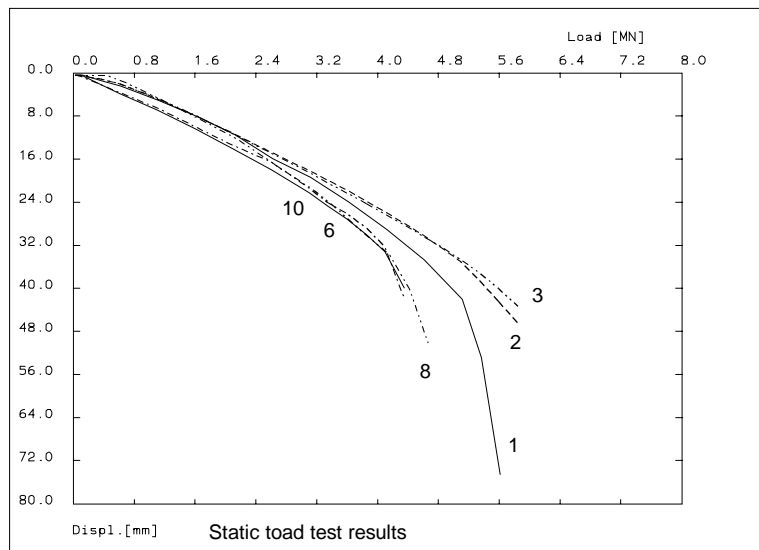


Fig 12. Overview of real static load-displacement diagrams

In Figure 12 the load-displacement diagrams of the real static load tests are presented.

The piles 1, 2, and 3 show a similar stiffness up to 3.2 MN. After 3.2 MN deviations occur.

Pile 1 shows a less stiffer behaviour than the other piles and has the lowest capacity of the three steel piles.

Piles 6, 8 and 10 show a similar behaviour.

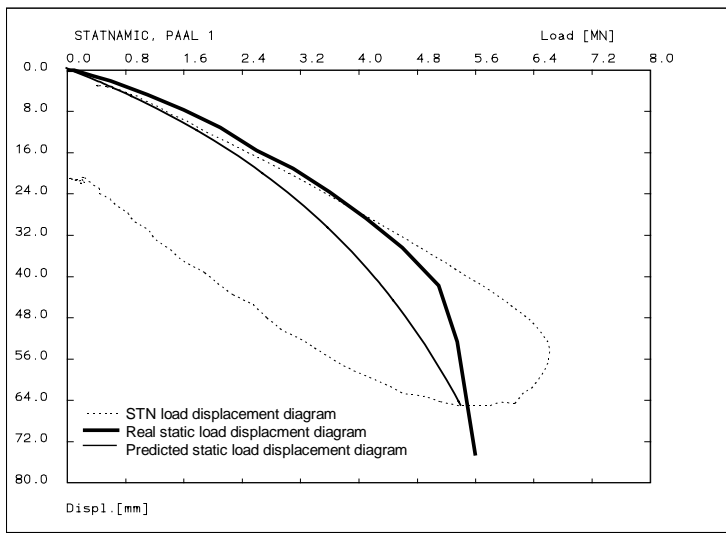


Fig 13. Pile 1, Predicted and measured static behaviour

For pile 1 the STN load-displacement diagram, the predicted static load-displacement diagram and real measured static load-displacement diagram for pile are presented in Figure 13.

The stiffness of the pile for STN is somewhat lower than the SLT stiffness. The static capacity at maximum STN displacement and static capacity from SLT agree well.

There is substantial permanent set after the STN test.

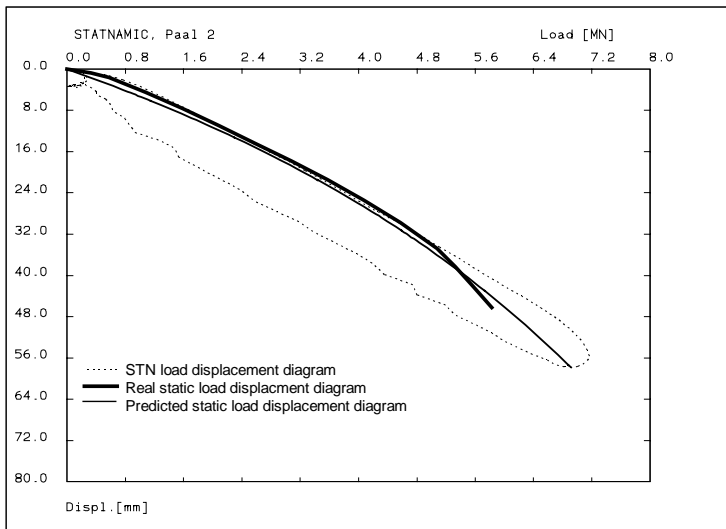


Fig 14. Pile 2 Predicted and measured static behaviour

For pile 2 the STN load-displacement diagram, the predicted static load-displacement diagram and real measured static load-displacement diagram are presented in Figure 14

The static loading curves from STN and SLT agree well.

The permanent set after STN is limited and the pile is still in the elastic range.

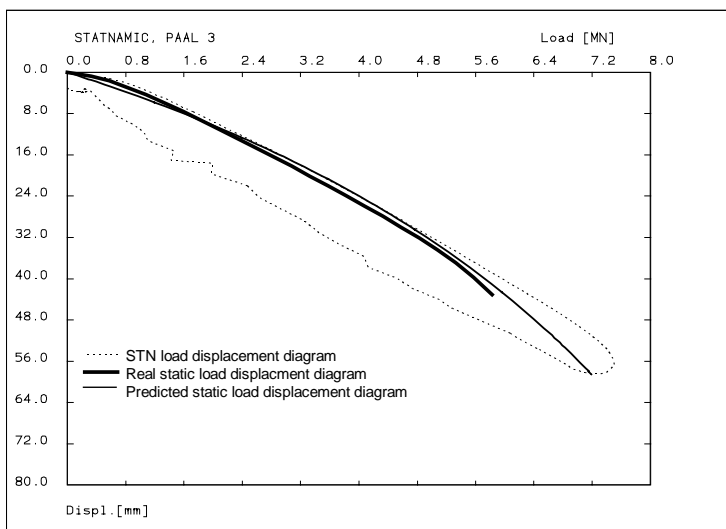


Fig 15 Pile 3 Predicted and measured static behaviour

For pile 3 the STN load-displacement diagram, the predicted static load-displacement diagram and real measured static load-displacement diagram for pile are presented in Figure 15

Also for this pile, the predicted and real measured static loading curves agree well.

The permanent set after STN is limited and the pile is still in the elastic range

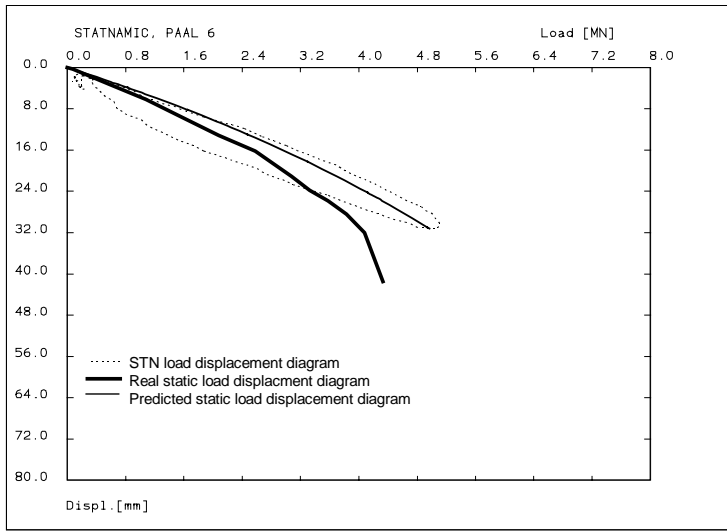


Fig 18 Pile 6. Predicted and measured static behaviour

For pile, 6 the STN load-displacement diagram, the predicted static load-displacement diagram and real measured static load-displacement diagram are presented in Figure 16

The predicted stiffness is higher than SLT. The static resistance at maximum STN displacement is 19% higher than SLT.

The permanent set after STN is limited and the pile is still in the elastic range.

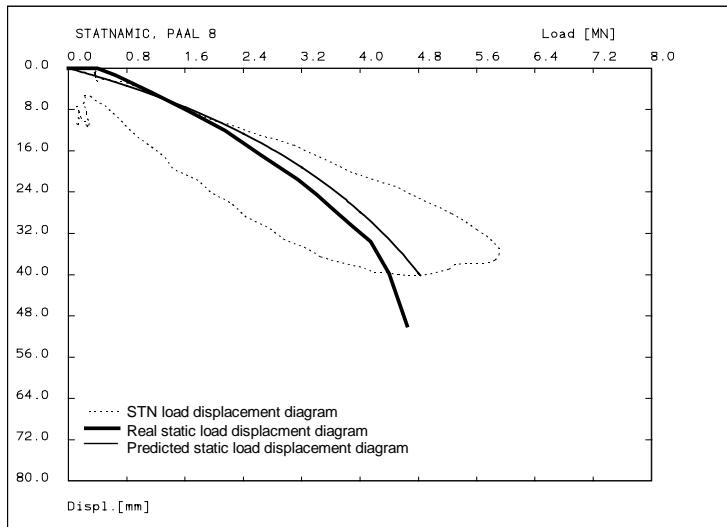


Fig 17 Pile 8. Predicted and measured static behaviour

For pile 8 the STN load-displacement diagram, the predicted static load-displacement diagram and real measured static load-displacement diagram are presented in Figure 17

The STN pile stiffness is lower up to 1.6 MN and somewhat higher after 1.6 MN. The static resistance at maximum STN displacement is 10% higher compared to SLT.

The permanent set is higher than for the two other precast piles. The STN curve has a larger area than for the other precast pile, which means that more energy by yielding of the soil is absorbed.

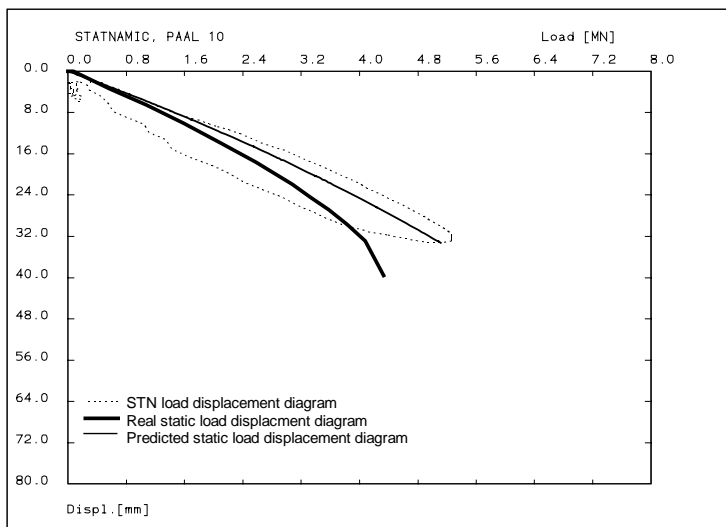


Fig 18. Pile 10. Predicted and measured static behaviour

For pile 10, the STN load-displacement diagram, the predicted static load-displacement diagram and real measured static load-displacement diagram are presented in Figure 18.

There is an increase of the pile stiffness. The static resistance at maximum STN displacement is 24% higher compared with SLT.

The permanent set after STN is limited and so the pile is only loaded still in the elastic range.

Pile no	Test date SLT	Test date STN	days between tests
pile 1	2-3-95	31-3-95	28
pile 2	27-2-95	3-4-95	34
pile 3	22-2-95	5-4-95	41
pile 6	9-2-95	28-3-95	46
pile 8	14-2-95	30-3-95	43
pile 10	20-2-95	27-3-95	34

Table 2. Test dates

6. COMPARISON STATIC AND STATNAMIC LOAD TEST RESULTS

For several test results, there is a good agreement between STN and SLT. For other tests, the piles stiffness and capacity from STN are higher than results from SLT. It should be kept in mind that straightforward comparisons between load tests are difficult or impossible. First, by the time difference between the performance which can result in an increase of soil resistance. In table 2 the test dates of SLT and STN are presented together with the number of days between the tests. Secondly, the STN tests are an extra loading cycle to SLT and an increase of stiffness and capacity can occur.

7. CONCLUSIONS

The following conclusions can be made for the steel piles. The steel piles 2 and 3 show good agreement between STN and SLT. For steel pile 1, the stiffness for STN after working load is somewhat lower than SLT. The capacity prediction agrees well.

The STN results of the concrete piles show a higher stiffness than SLT. The static capacities obtained from STN are 10 to 24% higher compared to SLT.

By comparing STN and SLT results it must be taken into account that the time difference between both tests and the performance of STN after SLT as a next loading cycle influences the load-displacement behaviour of the piles.

8. REFERENCES

Middendorp, P, Bermingham P., Kuiper B, 1992, Statnamic load testing of foundation piles. 4th International Conference on Stress Waves, The Hague, Balkema

Middendorp, P , Bielefeld, M.W., 1995, Statnamic Load testing and the influence of stress wave phenomena. First International Statnamic Seminar, Vancouver