PSEUDO STATIC PILE LOAD TESTER

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Abstract

For fast and economic testing of piles Fundex Piling and IFCO have jointly developed a new testing equipment: the Pseudo Static Pile Load Tester which is mounted on tracks and is able to execute full scale load tests under compression. Following paper describes the theoretical backgrounds and some test cases of this ready to use method.

General

An important question to be asked for any pile is, what is its real bearing capacity? Although static load testing is reliable, the major disadvantages are the high costs involved and the long time required. These reasons do not allow an often and regular use. Due to the commonly accepted Dutch cone penetration test in The Netherlands most engineers determine the pile bearing capacity by the method of Koppejan and others (also known as the 4D-8D method). This method has proven itself over the past decennia, however, recent disagreements were noted [1].

Many West European countries have standard rules for determining the actual bearing capacity and the quality control which requires a certain number or percentage of static load tests at major projects. A relatively cheap alternative for the static load test is the dynamic load test, testing the pile only for a few milliseconds. The major objection of this method is the fact that the measured bearing capacity is a combination of both a static and a dynamic component. By means of pile modelling, only specialist engineers are able to derive the static component from the analyses.

During the past few years new developments have improved dynamic load testing. It was expected that extending the loading time to a multiple period of milliseconds would substantially reduce the dynamic component of the measured bearing capacity. Such developments would simplify the interpretation significantly. These new quasi or "pseudo" static loading techniques emphasize the static element. Examples are Statnamic and the here described Pseudo Static Pile Load Tester (PSPLT).

Theoretical background

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The most important advantage of the dynamic load test versus a static test is that devices for reaction forces are not required, such as reaction piles or heavy kentledge. During dynamic load tests the force F is the result of a change of momentum. Its relation is presented by

$$\vec{p} = \int \vec{F} dt = mv_{pre} - mv_{post} \qquad (1)$$

in which

m = the mass used for the test and v_{pre} and v_{post} are the velocities of the mass, before and after the interaction with the pile

In the equation the principle of action = negative reaction can be recognised. The action force is exercised on the pile and the reaction force on the dropmass. Equation (1) is simplified by neglecting gravity, since this is very small related to the executed force during the load. Should gravity accelerate or decelerate the dropmass, equation (1) can be recalculated to a height with

$$v = \sqrt{2gh} \qquad (2)$$

in which
g = acceleration of gravity
h = height of the mass before or after the test

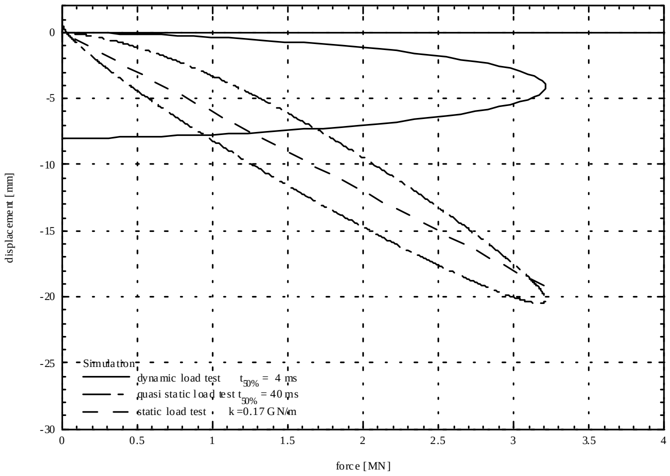

Figure 1. The load settlement curve calculated for a dynamic, a pseudo static, and a static load test. The parameters are: soil stiffness = 0.28 GN/m, soil impedance (= damping)= 1.3 MNs/m, wave velocity = 4180 m/s, pile length = 16.4 m, pile area = 0.4x0.4 m^2 and the Youngs modulus= 42 GN/m^2.The force as a function of time is (1-cos(t)). The $t_{50\%}$ is 4 ms for the dynamic test and 40 ms for the pseudo static test.

During a dynamic load test the magnitude of the exerted force is comparable to the ultimate pile bearing capacity. Equation (1) shows the relation of duration of the load on the pile with the change of momentum. Extending the load time requires increasing mass or velocity. The duration indicates how "static" the load test is. A definition of this time is the duration of which the load is above a certain percentage of the maximum load. The percentage is usually 50 %, (so called $t_{50\,\%}$). When different systems are to be compared identical definitions for this time scale must be used.

The duration $t_{50\%}$ of a loadtest performed with Statnamic can be calculated using formulas (1) and (2). For the mass it is advised to take 5-10 % of the pile's ultimate bearing capacity [9], velocity v_{pre} = 0 m/s, assuming that the mass reaches a height of 1.5 m, and that the force as function of time has a triangular shape, then the duration of the load is:

$$t_{50\%} = \frac{m\sqrt{2gh}}{F_{ultimate}} = \frac{\frac{0.1F_{ultimate}}{g}\sqrt{2gh}}{F_{ultimate}} = 0.1\sqrt{\frac{2h}{g}} \approx 50ms \qquad (3)$$

in which

$t_{50\,\%}$ = is the duration where the force exceeds 50 % of the maximum force

$F_{ultimate}$ = the ultimate pile bearing capacity

The forcepuls deployed to the pilehead generates a shock wave into the pile. The travelling time of the wave from the pilehead to the piletoe and vice versa causes a delay in the response to the reaction forces of the subsoil. This is why for loads of relatively short duration only the velocity of the pile head is used for the analysis instead of displacement. The duration of the load should be compared with the wave travelling time. A load becomes quasi-static when:

$$t_{50\%} >> \frac{2l}{c} \qquad (4)$$

in which

l = the pile length

c = wave velocity in the pile (approx. 4000 m/s for concrete, and 5100 m/s for steel)

Figure 1 shows calculations of load-settlement curves for three loading techniques on a simplified pile-soil model. The pile has a length of 16.4 m, a cross-sectional area of 0.4 x 0.4 m², and a wave velocity of 4180 m/s. The piletoe reaction force is generated by a pure elastic spring, and the pile has no side friction. From fig. 1 can be read that the quasi-static testmethod very well approaches the elastic load-settlement curve. The shape of the looped curve is caused by the time delay between load and settlement and does not relate to the shaft friction, since that is lacking in this simple model.

Pseudo Static Pile Load Tester

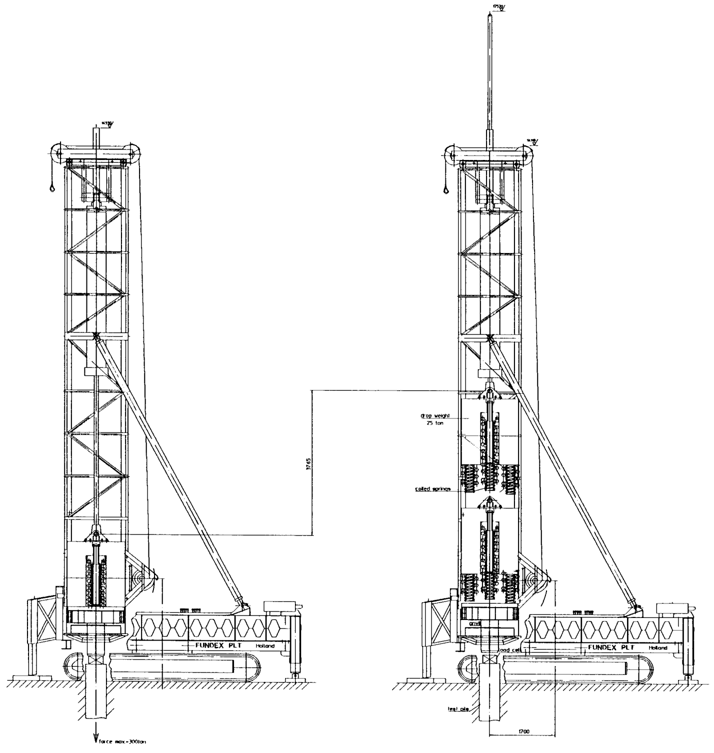

Figure 2. Drawing of the PSPLT.

The PSPLT is especially designed to execute quasi-static load tests (fig. 2). The load test is carried out by means of dropping a heavy mass with a coiled spring assembly from a predetermined height onto a single pile. After the hit the mass bounces and is caught in its highest position. The principle of the PSPLT was previously described in [3]. According to equation (1), this loading method gives almost a double momentum change using the mass efficiently. Efficiency is further increased by catching the bouncing mass, which makes larger dropheights possible. This also avoids further hindrance to the test and the measurements. The instrumentation for the test consists of a load cell and an optical displacement measuring device. The load cell which is placed on top of the pile is almost identical to the one used during static load tests. Pilehead displacement is recorded with the optical device mounted on a tripod at a distance of approx. 10 m from the pile. It is furthermore equipped with a geophone to monitor vibrations of the tripod during the test. All measured signals are immediately processed by a computer and presented in relevant graphs.

The execution of a test is as follows: the PSPLT is brought to the test site by a low-loader. It moves on its tracks to the testpile, whose pile head has previously been prepared. When the rig is positioned and the measuring devices are attached the test can start. First a static load test is carried out with the weight of the dropmass. Then subsequently a number of loads are deployed to the pile by dropping the mass from increasing heights onto the pile. With the output of results a quasi-static load-settlement curve is produced. Then the next pile can be tested. It is possible to load-test a significant number of piles per single working day. With proper preparations on the test site and the pileheads more than 10 piles daily have been tested.

The load of the PSPLT can be described by a simple model: a mass *m*, with a spring *k*, is dropped from a height *h* onto a rigid base. The values of *m* and *k* are respectively 25.000 kg and 8 MN/m, height *h* is equal to zero when the spring touches the base. The maximum force is then represented as:

$$F_{\max} = mg\left(\sqrt{\left(\frac{2kh}{mg}+1\right)}+1\right) \approx \sqrt{2mgkh} \qquad (5)$$

The duration of the load is between

$$175ms \approx p\sqrt{\frac{m}{k}} > t_{50\%} > \frac{2p}{3}\sqrt{\frac{m}{k}} \approx 117ms \qquad (6)$$

Figure 3 shows equation (5) in a graph with the parameters of the PSPLT. Figure 4 shows the force as function of time. The duration of the load $t_{50\ \%}$ has a small dependence of the dropheight. The above described model is a good approximation of the force exerted by the PSPLT as a function of time. However, an error is caused by the simplification of the coil springs being massless. The assumption of a rigid base is justified, because the displacement of the pile during loading is far less than the compression of the coiled springs. A complete model was also made, including the spring mass [4]. The mass effects of the coiled springs in the PSPLT are minimized by using additional rubber springs and by creating a time delay between subsequent coils hitting the base plate.

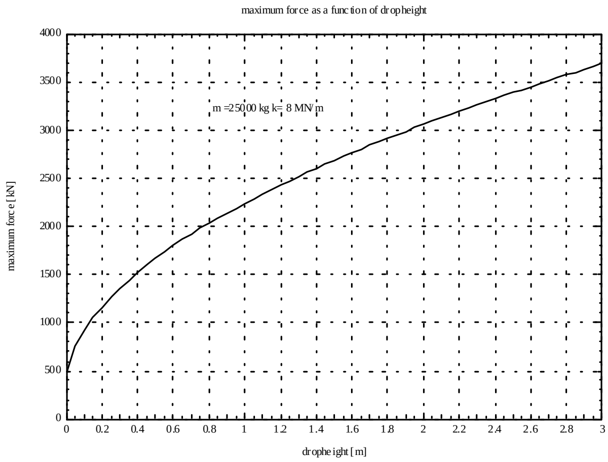

Figure 3. Maximum force as a function of dropheight.

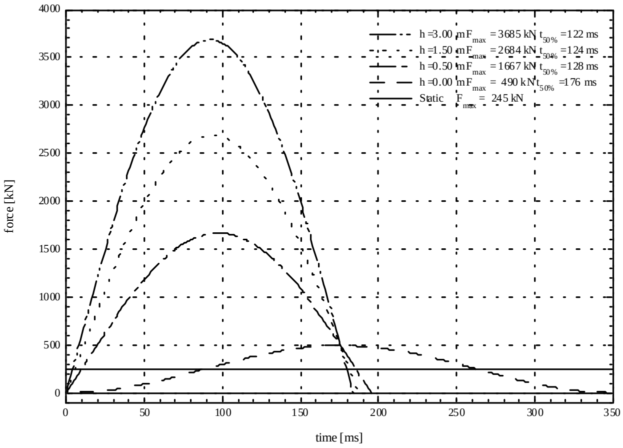

Figure 4. The force as a function of time for different dropheights. The insert shows the different values for $t_{50\%}$ ..

Results and interpretation

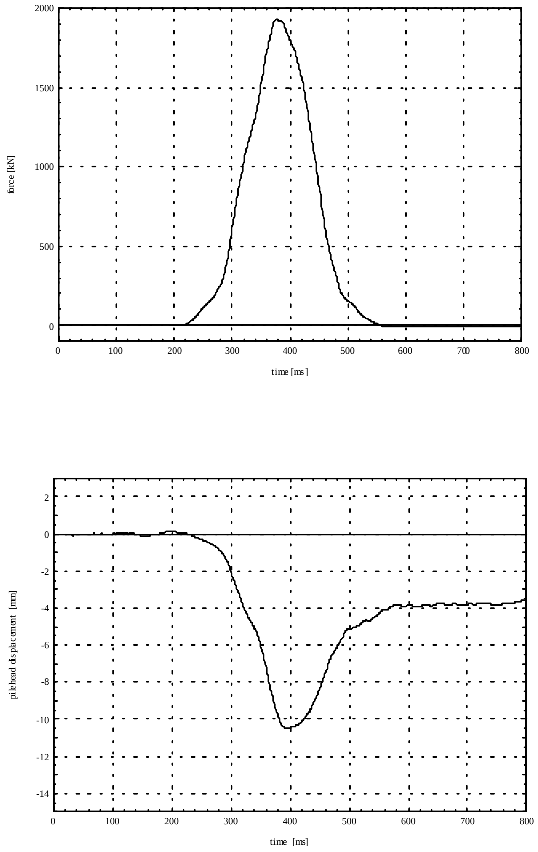

Figure 5. The measured force exerted by the PSPLT and the measured displacement of the pilehead as a function of time.

At various sites in The Netherlands, Belgium and Germany the PSPLT has been used successfully. Some results of these tests are presented in figures 5, 6 and 7. When these test results were matched with available static load tests, it was observed that the PSPLT results were some-what optimistic for the ultimate pile bearing capacity. However, the tests gave a very good indication with respect to individual differences. In other words: better performance measured by the PSPLT gave equally better results in the static load test. Especially in the elastic behaviour of the pile the load-settlement curve is identical to the load-settlement curve of the static load test. This phenomenon made it useful to find "heaved" piles [5]. The differences in stiffness between piles can easily be detected.

A difference between the results of both PSPLT and static load tests at ultimate bearing capacity was not expected. The Smith-model [6] is generally used to interpret the influence of the velocity for dynamic tests. This model predicts for quasi-static pile load tests a significant reduction of the velocity dependant component. The result from the quasi-static tests showed that the parameters for the model are not applicable. Therefore, results from tests in soils (like in The Netherlands) should be corrected, something which is apparently not required in cases where piletips are embedded in hard strata or rock [7]. This correction can be made by using the models from "short term" dynamic load tests with new values for the parameters [8]. Furthermore, a new simplified model for correction to ultimate bearing capacity is proposed [9].

Experience gained with the PSPLT results show that the present models are not yet completely satisfactory. The creep behaviour of the bearing soil layer is not considered and this is a likely explanation why the measured ultimate bearing capacity derived from the PSPLT is larger than measured with a static load test. The same phenomenon is also observed when bearing capacities were obtained by means of fast

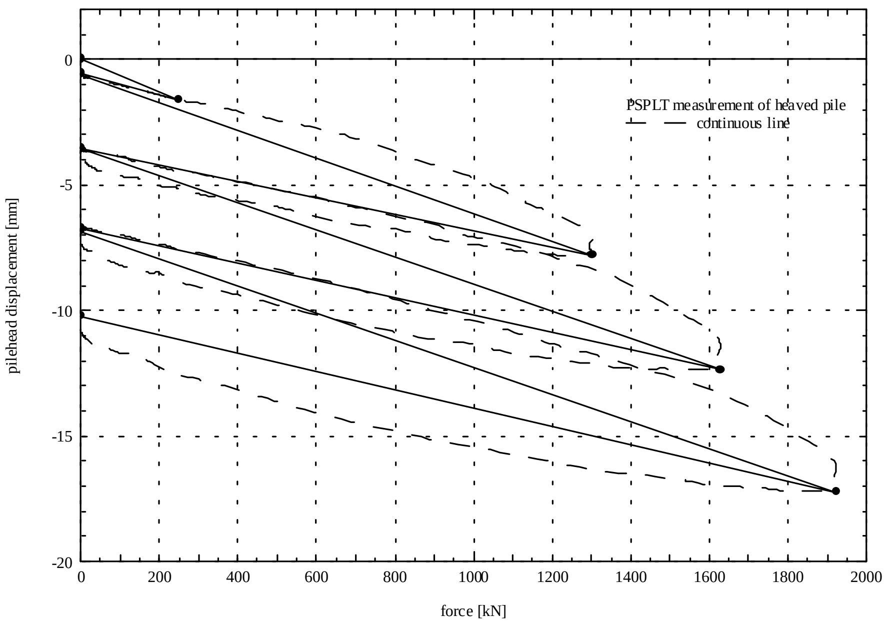

Figure 6. The load displacement curve generated by four consecutive dropheights. The continuous load settlement curve is also shown.

executed static load tests (15 min.). Such tests showed better (=higher) results, compared to standard static tests [10].

Further investigation will be necessary to find a better relation between the results of the pseudo static load test and those of the common static test. The lack of adequate and useful comparison tests is the reason that such a match has not yet been well defined.

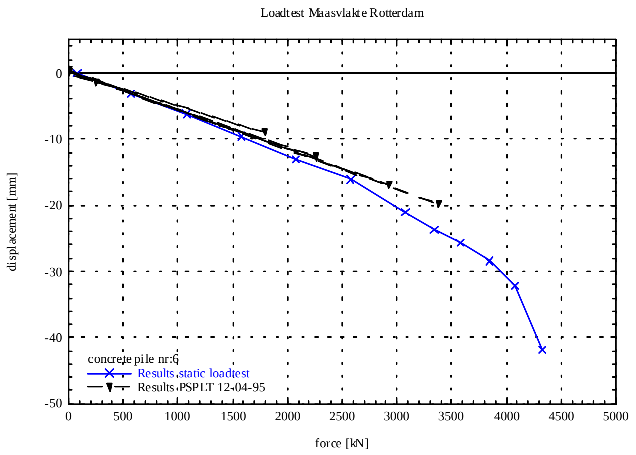

Figure 7. Comparison between a static load test and a measurement with the PSPLT.

Conclusion

In checking the bearing capacity of piles the PSPLT method is quick, cheap and useful. It offers the possibility to identify the stiffness and bearing capacity of individual piles in a foundation. So far it is not yet possible to measure static ultimate bearing capacity with a sufficient degree of accuracy. However, it may be expected that future investigations will make this possible.

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