Pile Load Tests

According to DIN 1054 and Eurocode 7, the purpose of pile load testing is to reliably determine the bearing capacity as well as the settlement behaviour of single piles for a particular project. We offer a wide range of testing equipment which meets the above requirements, thus helping to ensure a commensurate and technically valid evaluation of results such as is demanded in DIN 1054.

As Fig. 1 shows, two factors contribute to **the load bearing capacity** Q of a pile:

- The pile end force Q_S acting on the foundation at the foot of the pile
- The pile skin force Q_r acting as friction against the sinking of the pile

Tension piles are affected only by skin friction.

Hence the bearing capacity of a compression pile as a function of the settlement s is derived from

$$Q(s) = Q_s(s) + Q_r(s)$$

or

$$Q(s) = A_F \, \sigma_s(s) + \Sigma \, \Delta A_m \cdot \tau_m(s)$$

where

A_F = Area of pile end = $\pi r^2 \left[m^2\right]$
σ_s = Pile tip pressure $\left[MN / m^2\right]$
A_m = Pile skin area in load-bearing soil $\left[m^2\right]$
A_m = $2 r \pi l_o$ (l_o = length over which skin friction is effective)
τ_m = Skin friction $\left[MN / m^2\right]$

Depending on which factor is dominant, the term "end bearing pile" or "friction pile" is used.

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The second objective of pile load testing in addition to determining the bearing capacity of a pile is to determine its **settlement behaviour**. If a compression pile settles "significantly" in a loading test or if a tension pile rises "significantly" in a pull-out test, the limit condition with load Q_g is reached. A pile's safety η is related to this load limit Q_g as follows:

$$\eta = Q_g / Q_{ul}$$

The load limit Q_g is marked on the load/settlement or load/heave curve where the "significant" settlements and heaves occur. With large-diameter piles, the test load (at least twice as high as the subsequent structural load) often fails to result in a limit load Q_g. To comply with DIN 1054 in these cases it is sufficient to conduct the load test up to settlement of the pile head equal to four-fold the settlement at design load. Other standards recommend a settlement limit of 2.0 cm for bored piles and 0.025 d (in cm) for driven piles in such cases.

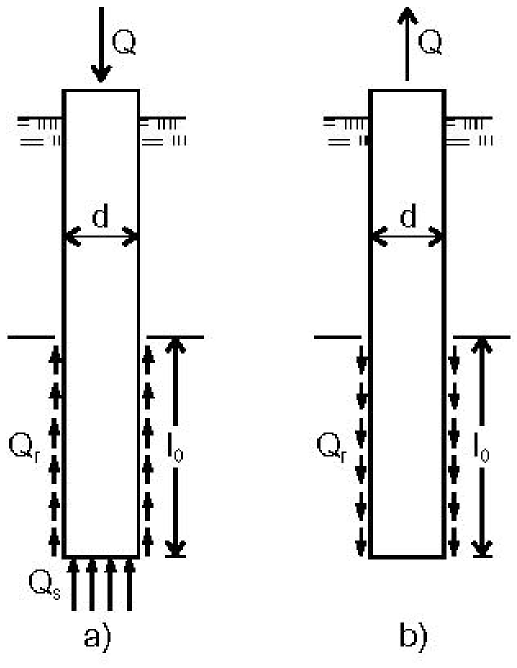

Fig. 1 Bearing capacity Q of a compression pile (a) and a tension pile (b).

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The **loading device** normally used for pile load testing purposes is a hydraulic cylinder acting against a yoke (see Fig. 2). The yoke itself is anchored to the ground by a number of anchors or tension bars. The distance between the anchors or bars and the pile should be at least 2.5 m or four times the diameter of the pile. In some rare cases, a dead weight is used as the yoke. The cylinder yoke must be designed to withstand loads of at least 1.1 times the maximum test load.

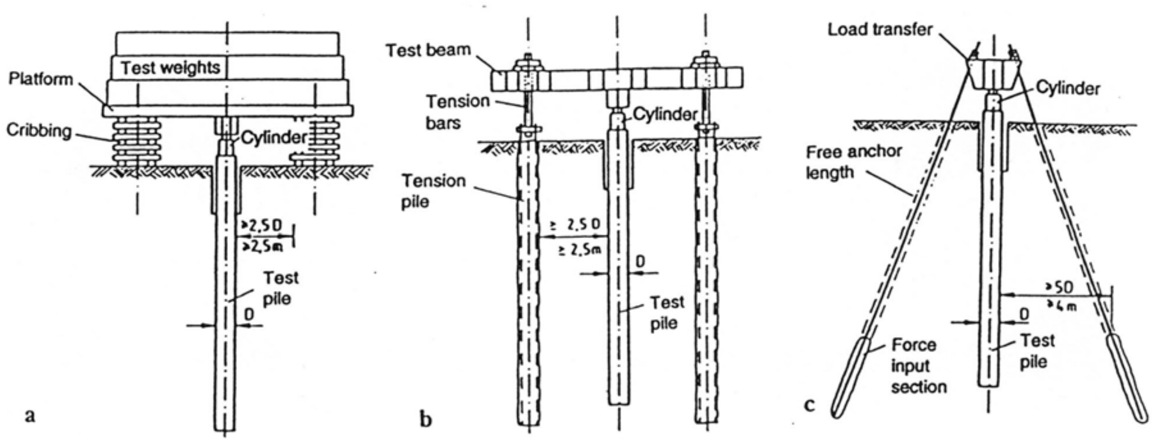

Fig. 2 Schematic presentation of the test setup for conducting a vertical load test with minimum distances between the loading device and the test pile for: a) Weight supports, b) Tension piles, c) Radially arranged, grouted expansion anchors (according to Working Committee 5, DGEG, 1993)

With a useful piston area of 228.59 cm² and at the maximum hydraulic pressure of 450 bar, the hydraulic cylinders HP 100/200 exert an effective force of

$$Q = (A \times p)/100$$

or

$$Q = (228.59 \times 450)/100 \text{ kN}$$
$$= 1.028.65 \text{ kN}$$

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Five such cylinders f. e. can be combined in a group able to exert a test load of 5 MN. Groups of just three cylinders or of more than five are also possible. These cylinders have a piston travel of 200 mm.

It is convenient to have the oil pressure in the cylinders generated by an electrically working hydraulic drive unit with a minimum capacity of 1 litre/minute. This should be able to supply the cylinders with sufficient hydraulic oil and thus maintain constant loading even for large pile head displacements, as is stipulated in DIN 1054 for the various test phases. An electric control circuit, which continually compares a selected pressure level with the actual pressure in the hydraulic circuit, keeps the load constant.

The test load is measured by either an electric or hydraulic load cell, which in either case should permit remote reading and comply with accuracy class 1. A spherical seat is located between the yoke and the load cell to protect it and the cylinder.

Vertical displacements of the pile head are measured at at least three points by electric transducers. The horizontal displacements should also be measured at the same three points in order to check for centric loading of the pile. The transducers should have a reading accuracy of ± 0.01 mm. The transducers are mounted on a measuring bridge which must be set up so as to suffer no displacement itself. To make sure this condition is fulfilled, levelling measurements have to be taken from a fixed point installed some distance away. The levelling should be done to an accuracy of ± 0.3 mm, which is generally no problem for a self-adjusting leveller with a plane plate micrometer attachment.

End bearing and skin friction

To determine the skin friction between the pile and the foundation, the pile's shortening or strain is measured at as many depths as possible. We offer three options for this purpose (Fig. 3):

- The multiple-point rod extensometer
- Sliding micrometers
- Strain sensors

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The **multiple-point rod extensometer**, with measuring rods anchored at up to six different depths, can either be fitted and cast in place at the centre of the reinforcement cage during production of the pile or be inserted and grouted in a subsequently sunk borehole. The displacements of the measuring rods are recorded by electric transducers with a measuring accuracy of ± 0.01 mm. This alternative requires the load distribution plate to have a central opening and three or more hydraulic pistons to apply the load, as only this arrangement will enable the displacement to be measured at pile centre.

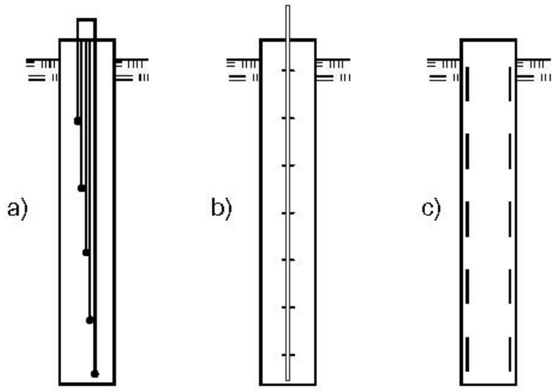

Fig. 3 Schematic presentation of the various options for measuring pile strain and pile shortening.
a) Multiple-point rod extensometer, b) Sliding micrometer, c) Strain sensor (three each per measurement level)

A similar test setup must be available if a mobile extensometer probe **(sliding micrometer)** is to be used instead of a fixed extensometer rod system. A plastic tube with an arrangement of measuring rings spaced 1 m apart is installed in the pile. Any changes in the spacing of these rings is measured by the sliding micrometer probe with a reading accuracy of 0.001 mm. For the probe to move in and out during the test, the pile head plate must have an opening of at least 50 mm. The sliding micrometer test setup has the great advantage of being able to measure the shortening or strain of the pile continuously from one meter to the next. It is usual to take one sliding micrometer measurement for each loading stage of the pile test.

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Particularly when test piles are to be integrated in the subsequent structure and there are reasons for wanting the pile strain and shortening measurements to continue, we recommend the use of **strain sensors** for the measurement of displacements between fixed points between one and three meters apart by high-resolution displacement sensors (f. e. measuring range ± 1 mm, resolution 0.002 % of range, measuring accuracy ± 0.002 mm). Chains can be formed by joining up several measuring elements with waterproof plug-type couplings.

The **force acting at the foot of the pile** is measured by a pressure pad fastened to the bottom part of the reinforcement cage. Before inserting the pressure pad you must cast a 30 - 40 cm layer of concrete at the bottom of the borehole to support the pressure pad. The effective diameter of this pressure pad must be smaller than that of the pile casing. This annular gap has to be covered, therefore, with a rubber ring to stop concrete bridges forming between the cast base and the actual pile and corrupting the peak pressure measurements. The pressure pad is co-ordinated in diameter with the dimensions of the pile and filled with oil. A piezoelectric sensor measures the increase in pressure induced in the oil by the pile loading.

All pile load test data are scanned and logged by computer as shown in Fig. 4. The various loading stages are set at the stabiliser and each loading stage is maintained until the settlements subside to 0.02 mm/min. The results of a pile load test are shown in Fig. 5.

Just a final word concerning the accuracy of measurements: Annex A of DIN 1054 stipulates that "all instruments and the loading setup must be calibrated prior to carrying out a series of tests". This implies that the measuring and loading equipment must be calibrated by an official institute.

This requirement, we feel, is completely unrealistic. Should the contractor insist on it nevertheless, he must not forget that delivery will take several weeks longer and that the costs of the instrumentation will rise considerably. (For official calibration of a load cell you have to pay € 400.00 at the moment, for a displacement sensor approximately € 300.00). Instead we suggest that the customer visits our factory and makes his own picture of our quality standards in the production and calibration of our instrumentation. If he wishes, he may also have random calibration tests carried out.

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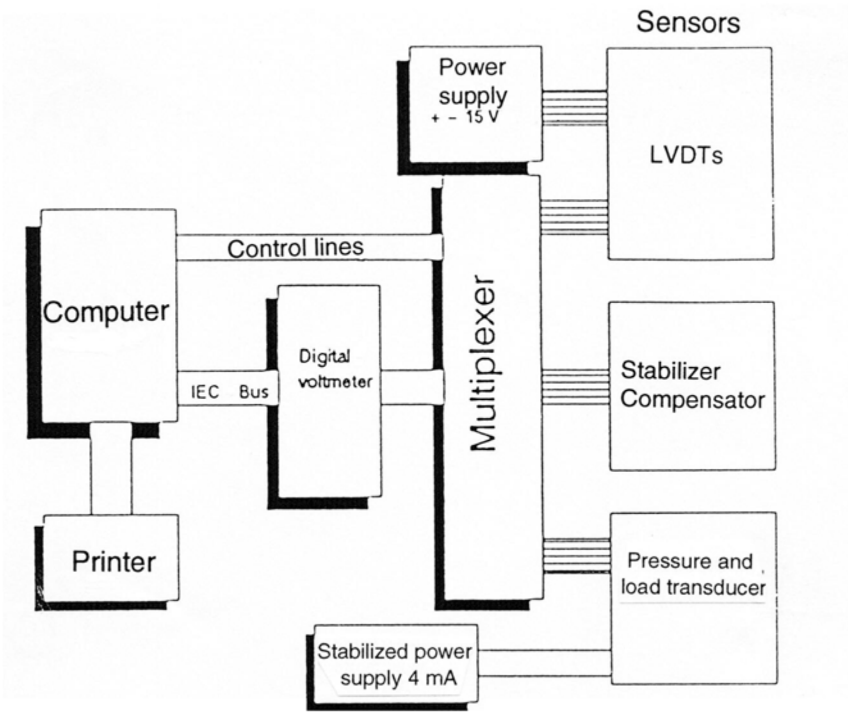

Fig. 4 Schematic of test data scanning and acquisition during the pile loading

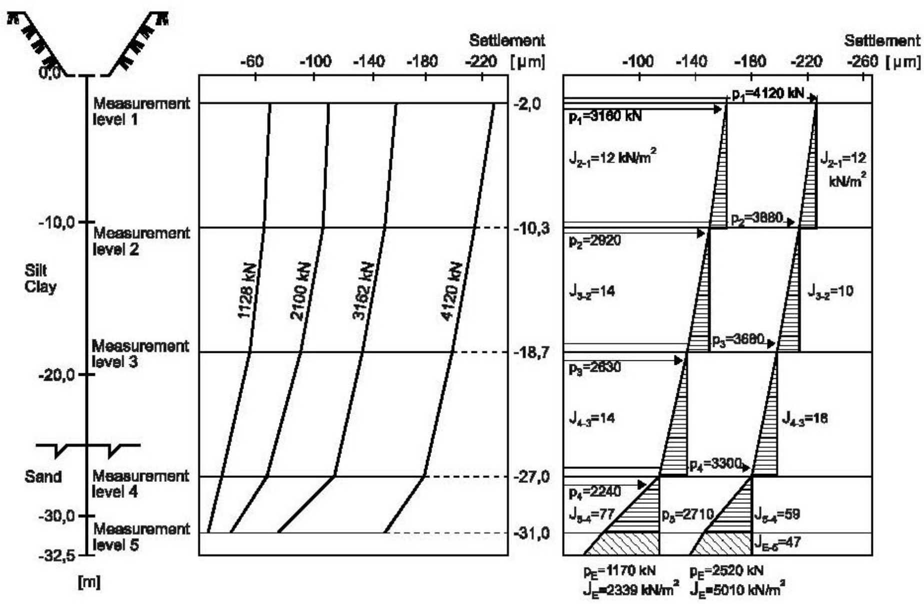

Fig. 5 Results of a pile load test in which the load dissipation has been measured by strain sensors

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In our experience the quality of **tender documents** for pile load tests fluctuates greatly. Sometimes specifications are made into the smallest detail, while other tender documents simply state: "'Two pile load tests in accordance with DIN 1054. Construction of the test piles to be billed separately."

Such tenders leave bidders with insufficient scope for calculation. It is impossible to compare offers, and in not a few cases the results are unpleasant disputes between customer and supplier which could easily have been avoided.

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