

# The pile inspector, a new quality tool to read pile base enlargement of bored piles

## L'inspecteur de pieux, un nouvel appareil de contrôle pour mesurer l'élargissement à la base de pieux foré

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**ABSTRACT:** The pile inspector allows to measure the geometrical enlargement of pile bases during the construction phase. Either connected to the kelly bar or attached to the service crane, the pile inspector is lowered into the drilled hole and measures the geometrical profile at the pile base, using 4 prestressed arms. Once the pile inspector is lifted out of the drilled hole, the installed reader transfers the gained data to the computer of the site engineer. The installed visualisation programme allows to visualise the results within a short period of time and displays the shape of the base of enlarged pile and the profile of the pile shaft.

**RÉSUMÉ:** L'inspecteur de pieux permet de mesurer l'élargissement géométrique des bases de pieux pendant la phase de construction. Connecté à la tige kelly ou à la grue de service, l'inspecteur de pieux est descendu dans le forage et mesure le profil géométrique de la base du pieu à l'aide de 4 bras précontraints. Une fois que l'inspecteur de pieux est sorti du forage, le lecteur intégré transfère les données acquises à l'ordinateur de l'ingénieur sur site. Le programme de visualisation installé permet de visualiser les résultats en peu de temps et affiche la forme à la base et le profil du pieu.

**Keywords:** bored pile; base enlargement; increased load capacity; shaft profile; pile inspector

## 1 INTRODUCTION

Pile base enlargement allows to increase the design load for bored piles. Areas of application for base enlarged piles are the transfer of high individual and surface construction loads into the ground.

The enlarged bored pile contact area enables an adjustment to the actual pile load and can therefore enable a significantly more favourable pile layout considering the internal pile load capacity. It may therefore be possible to replace a group of piles with a base enlargement and thus save pile concrete. The increased pile contact area also leads to reduced pile shaft diameters at lower drilling depths.

The technical developments in recent years like post-grouting or deep soil mixing have pushed pile base enlargement into the background. Another reason why the design of a bored pile with base enlargement is not often used is the increased additional effort involved in checking the actual geometry of the enlarged pile base.

With the help of the new construction of the pile inspector, the geometry of the base expansion can now

be measured and evaluated during the production of the bored pile.

## 2 GEOTECHNICAL REQUIREMENTS

According to EA-Pfähle 2012 [Chapter 2.2.1.6], base enlargement can only be created in sufficiently stable soil. In unstable soils or if the expansion area is below the groundwater level, the base expansion must be secured with the help of a bentonite or cement suspension.

The geometry is limited and depends on the stability of the ground conditions. For non-cohesive soils or cohesive soils, limit values for the ratio of foot height to foot projection are set in accordance with EA-Pfähle [Chapter 5.5]. The ratio values are:

- In cohesive soils 2:1
- In non-cohesive soils 3:1

The extent of expansion is determined based on the soil encountered and the boundary criteria according to the static requirements.

The pile design postulates a complete filling of flawless concrete into the enlarged pile base.

## 2.1 Construction of the pile base enlargement

The type of bored pile depends on the existing soil and the groundwater conditions. Various drilling methods can therefore be used to produce the borehole. These include kelly bar drilling, auger drilling, displacement drilling, either with water or bentonite slurry support.

Depending on the encountered soil conditions, the borehole must be supported with casings or with partial casings. After completing the drill hole, the reaming tool is connected to the kelly bar. (see Fig. 1).



Figure 1. Pile base cutter in operation

After reaching the designed depth, the cutting arms of the pile toe cutter are extended by pressing vertically with the kelly bar. The removed drilling material is collected in the drilling bucket. In EA-Pfähle 2012 [Chapter 2.2.1.6] the geometry of the pile base produced is described as a truncated cone with a dome-shaped base and a lower cylindrical extension.

## 2.2 Evidence of pile base enlargement

There are several technical options available for verifying the enlargement of the pile base, which are usually carried out in combination.

Verification methods when producing the pile base expansion are:

- Climb measurement control The contact angle of the measuring arms, which are evenly distributed at a 90-degree angle across the cross section, is measured (see Fig. 3). The

arms are preloaded via springs and are released by a predetermined signal.

- Ultra-sonic profile reading
- Geotechnical confirmation
- Depth adjustment
- Concrete volume balancing

After the construction of the pile, the following methods are possible:

- Temperature distribution along the pile axis
- Pile load tests

When comparing the concrete volume in relation to the rise of concrete level, a first conclusion of the geometry of the pile base can be drawn, however no remediations or corrections are possible. The actual shape of the pile is unknown until the pile has been concreted.

A new approach to verify the geometry of the pile base is provided by the pile inspector which can verify the generated geometry of the pile base via the hydrostatic pressure recording and the angle measurement of the measuring arms. The following chapter goes into more detail about the manufacturing process and the use of the pile inspector.

## 3 PILE INSPECTOR

The pile inspector is a newly developed measuring concept that mechanically records the borehole wall and records its depth. The pile inspector is comparable to a drilling tool. After reaching the final depth, it is coupled to the kelly bar of the rotary drilling rig via the kelly box and lowered to the embedment horizon (see Fig. 2).

The measurement data is saved in the pile inspector. The measuring run takes place from bottom to top. Both the cased and uncased part of the hole as well as a possible foot extension can be accommodated. The measurement accuracy is so precise that the transition from the uncased to the cased bore can be recorded. There is no coupling of the pile inspector with the data acquisition of the rotary drilling rig. The depth measurement required for later evaluation takes place in the pile inspector, which registers the depth using hydrostatic pressure sensors.

After the end of the measuring cycle, the pile inspector is pulled out of the borehole and the data transfer from the built-in measuring box to the project engineer's notebook takes place immediately using bluetooth technology.

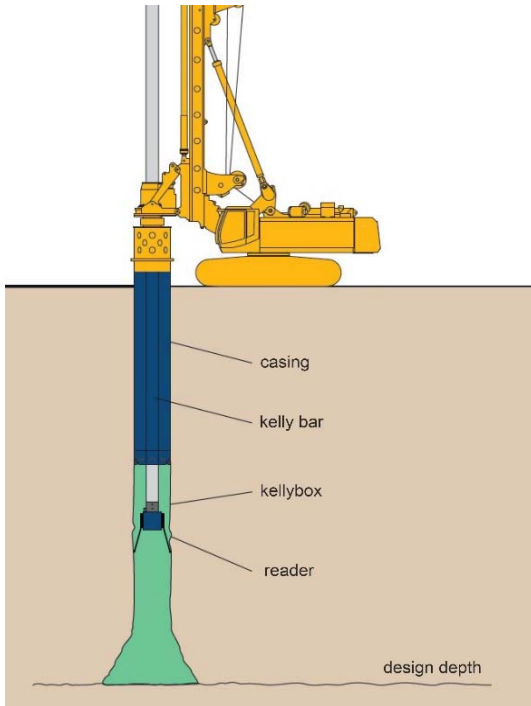


Figure 2: Use of the pile inspector

In practical terms, this means that the pile inspector is placed at the bottom and remains there for a period of approximately 2 minutes. The associated constant pressure triggers the pre-stressed joints and the arms are pressed against the wall (see Fig.3) with spring force. The joints are electrically connected to the data logger and are transferred to the central unit. The angle that the arms make to the wall is the relevant measurement that is recorded to capture the distance to the wall of the hole. The angle detection is linked to the self-sufficient depth measurement, so that the measured angle is always depth-related. Contact with the wall occurs via rollers, runners or contact strips.

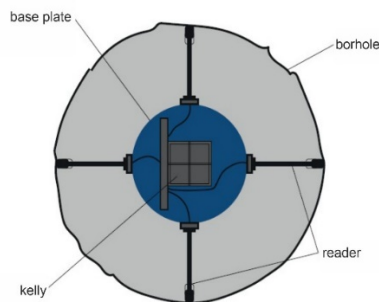


Figure 3: Arrangement of the measuring arms

After the pile has been expanded by the pile base cutter, the pile inspector is lowered into the depth and the arms are triggered to unfold. The lowering of the pile inspector is not necessarily linked to the kelly bar of a rotary drilling rig, but can also be done using a service crane. With the exception of the upward

pulling force, no forces have to act for the measuring process. What is important is the change in angle that has formed in the transition area between the expansion and the shaft profile.

This means that the essential parameter for the pile base expansion can be measured. In fact, the pile inspector records three pile sections, namely the opening angle of the pile base expansion, the contour of the uncased pile shaft and the cased part. The transition to the cased part will be discretely measurable.

The specific dimensions for the pile inspector have been implemented in steel construction drawings (see Fig. 4). The control connection to the drilling rig is made via the kelly box. The data logger with the battery unit to power the sensors is located centrally. A total of 4 arms can be connected. The length of the arms can be adjusted on site. The main frame of the pile inspector is a steel structure. The attachments are aluminum components. The entire construction is transported on a carrier pallet. The energy is supplied by batteries that are charged before use. The duration of the energy charge allows operation of 8 hours. The construction has been designed for drilling operations using appropriate spacers and protective profiles.

The geometric details of the pile inspector and the measuring distances can be found in Figure 4 below. The construction is designed so that the pile inspector fits into a casing with a diameter of 900 mm. With a maximum arm length of approx. 115 cm, an expansion of up to 218 cm can be recorded. The support structure below is designed so that sedimentation residues can be driven through. This mechanical form of scanning offers the advantage that the measurement recording is independent of the slurry properties and the measurement can therefore be carried out either before desanding or after desanding.

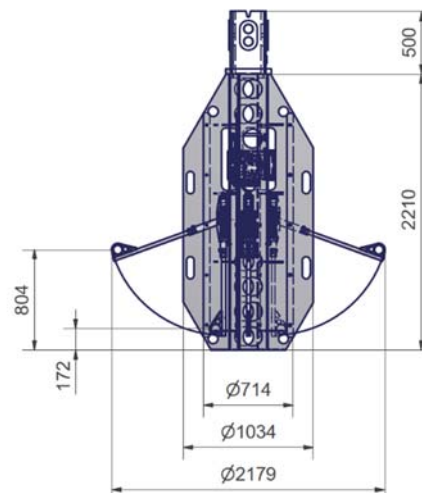


Figure 4: Technical dimensions of the pile inspector

### 3.1 Data transmission and visualization of the measurement data

The measurement data is recorded in the pile inspector and stored in the data logger. The construction site name, pile number, index of the measurement trip and the target depth of the drilling can be entered in advance. The measuring journey takes place from bottom to top.

The time, depth and angle of the measuring arms are recorded as measured variables. The measuring depth is recorded by a hydrostatic sensor that records the hydrostatic suspension pressure. This continuous measurement data recording is coupled to the angles of the arms at predetermined time intervals, which allows to determine the distance to the wall. This continuous data recording creates a continuous profile of the pile wall.

The start of data recording is set so that when the hydrostatic pressure stays constant for a defined period, the arms are unlocked and come into contact with the wall as a result of the pre-stressed arms. The measurement accuracy is very high. When the pile inspector is lifted out of the borehole, the data is transferred to the project engineer's notebook in already prepared graphics so that the relevant dimensions of the borehole contour can be read, right after the reading cycle. The measured distances are displayed individually for each arm. This graphical preparation of the measurement trip immediately afterwards allows a short-term decision to be made as to whether the trip needs to be repeated.

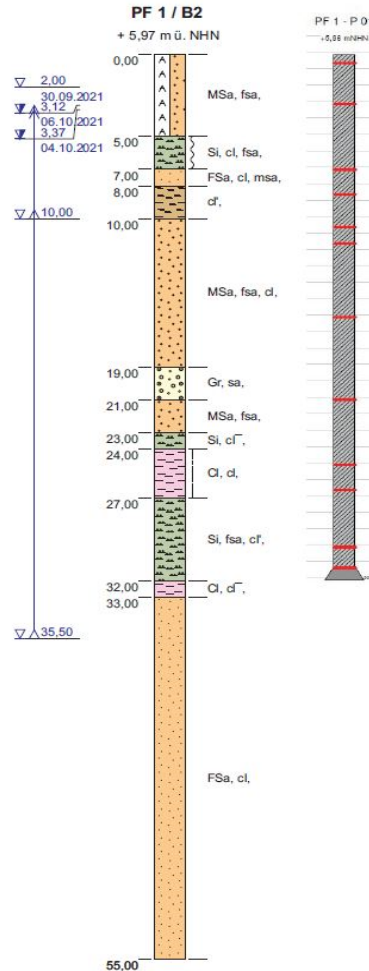


Figure 5: Idealized drilling including position of the bored pile with base expansion

## 4 GEOLOGY AND GROUNDWATER

Figure 5 shows the results of the site investigation and the possible position of the bored pile with the base expansion. The position of the pile is designed in relation to the geological profile and the pile length is determined based on this profile. It can also be seen from the drilling results that the pile base lays below the groundwater level and therefore stabilization with a supporting fluid is necessary during production.

## 5 CONSTRUCTION PROCESS

The following chapter introduces the construction process for cutting the pile base expansion. Once the designed borehole depth has been reached, the drilling tool is changed and the pile base cutter is mounted on the kelly bar of the drill rig. On the planned depth of the pile, the cutting blades extend via the vertical force of the kelly and thus create the rotationally symmetrical pile base. Following the expansion, the pile cutter is removed from the borehole again.

A detailed manufacturing sequence is shown in Figure 6 and 7.

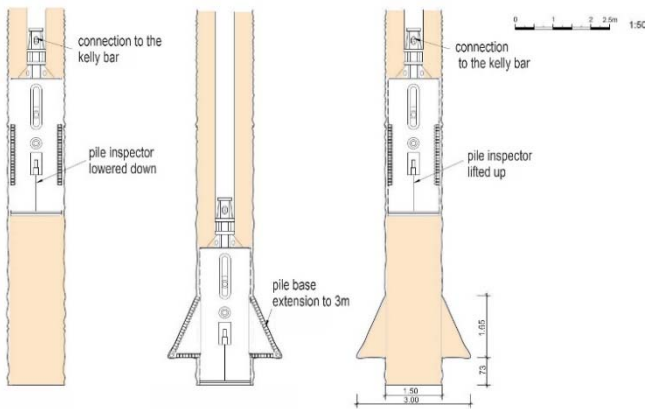


Figure 6: Expanding the pile base

After the expansion has been completed, the pile inspector will be connected to the drilling rig's kelly bar or a service crane and guided into the borehole. After reaching the target position, the measuring arms of the pile inspector fold out and record the geometry of the pile base that has actually been produced (see Fig. 7).

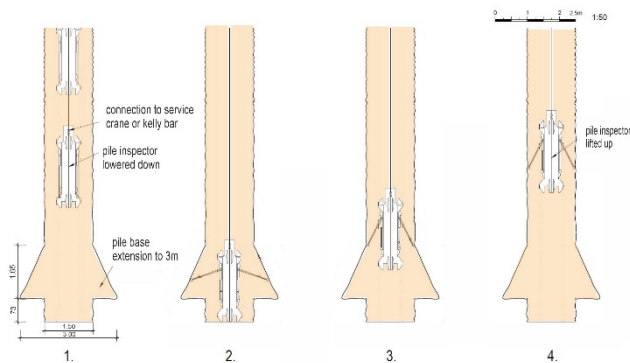


Figure 7: Measuring the pile base with the pile inspector

Due to the high measurement accuracy, deviations in the geometry can be identified during the installation process and corrected before the reinforcement cage is installed. It may be necessary to repeat the cutting and measuring process.

## 6 SITE APPLICATION

The field application offered the possibility to check the pile inspector in two operational ways, the kelly bar mounted (see Fig.8) and the crane mounted operation ( Fig.9). Since the drilling rig is essential for the overall progress on site, the crane application proved to provide significant time advantages. Once the final depth is reached and the pile base cut, the rig moves to the next drilling location, while the profile of the base expansion is scaled by the pile inspector.



Figure 8: Kelly mounted pile inspector

## 7 INTERPRETATION OF THE READINGS

The readings are taken at pre-determined depth and show the distance to the casing and to the cut profile at the pile base. A hydrostatic pressure meter in the pile inspector is calibrated on the actual drilling depth and allows to define reading levels at constant distances. The addition of opposite reading arms confirms the internal diameter of the casing.

At the level where the casing ends, an increase in pile diameter is recorded. All four arms prove this changeover at the same depth. The soil at this transition zone has been flushed out during the piling works with the drilling bucket.

The enlargement in the pile base area reaches over the pile shaft diameter and shows an uniform inclination of the cutting profile in all directions. This profile angle in combination with the construction drawings of the cutting tool enables a confirmation of the cutting width.



Figure 9: Service crane mounted pile inspector

## 8 ALTERNATIVE VERIFICATION METHODS FOR THE CONTOUR VERIFICATION OF BORED PILES

### 8.1 Thermal evidence

Alternatively, the base expansion of a concrete pile can be demonstrated by thermal measurements during hydration.

The sensors are most expediently mounted on the longitudinal reinforcement of the bored piles and read during the setting process. The distribution of the setting heat during the hydration time is recorded and evaluated across both the cross section and the pile length.

An even distribution is evidence of a planned enclosure of the sensors, lower temperatures indicate constrictions, cracks or imperfection of the concrete enclosure.

Obviously, the temperature development in the area of the foot expansion will be significantly higher than the normal range along the pile shaft.

### 8.2 Ultrasound measurements

The geometry of the wall can also be recorded using ultrasound measurements.

The sensor is positioned over the borehole before the pile is concreted and the ultrasonic transmitter is lowered into the borehole. The measurement results are visualized simultaneously with the measurement.

The ultra-waves run through the suspension and the running time is measured. The diameter can be derived indirectly from this. The purity of the suspension has a decisive influence on the speed of sound transmission.

## 9 CONCLUSIONS

The results of a pile base reading are displayed in Figure 10.

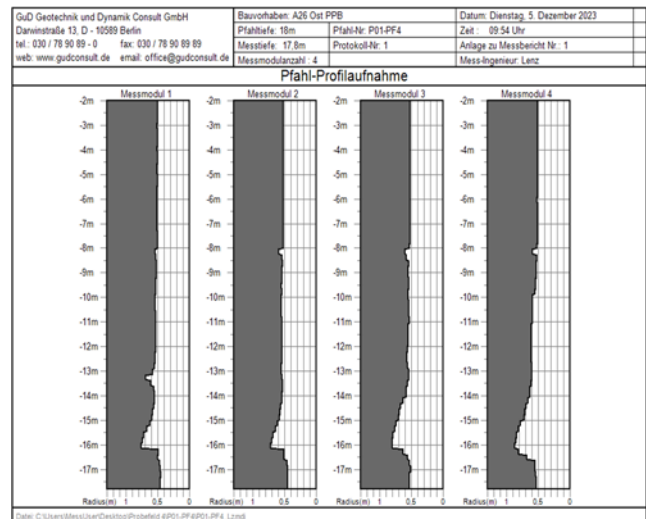


Figure 10: Visualisation of reading results

The presented pile inspector is a tailored form of evidence for the quality assurance of bored piles. This allows the geometry of pile base expansions and the borehole walls of the piles to be verified.

The kelly-adaptable measuring device allows it to be used effectively before concreting the pile, without significantly intervening in the construction processes. If necessary, the pile inspector can also be operated by a service crane.

The mechanical measuring principle enables high measuring accuracy. By linking the measurement data of the depth and angle of the measuring arms, the results can already be processed in the pile inspector and are available to the project engineer immediately after the measurement trip.

By using the pile inspector, the quality of the base expansion of bored piles can be assured. The associated higher utilization of the load-bearing capacity with reduced material use in the pile shaft and the simultaneous increase in tensile and compressive loads can sustainably improve the economic viability and sustainability of pile foundations.

## 10 REFERENCES

DGGT (2013). Recommendations on Piling. Ernst und Sohn