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Comparison of static and dynamic load tests on bored piles in glacial soil

COMPARISON OF STATIC AND DYNAMIC LOAD TESTS ON BORED PILES IN GLACIAL SOIL

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Abstract: BAW and BAM have performed a large scale comparison and calibration test on static and dynamic load capacity evaluation of bored piles in glacial sandy soil. The test was performed using eight piles at the BAM test site for technical safety at Horstwalde 50 km south of Berlin. The test area has been prepared and investigated in great detail using boreholes, cone penetration tests, pore pressure sensors and geophysical methods to assure controlled conditions for all piles and tests. The piles (10 m length, 0.9 m diameter) are mainly friction piles (low toe resistance) and have been checked by integrity testing. Five piles have been tested by five contractors using the dynamic method in a blind experiment, the other ones piles by static load and/or later on by the dynamic method. Some piles have been equipped with additional fibre optic instrumentation which proved to be robust and helpful in interpreting the results of static, dynamic and integrity tests. We have experienced a deviation of the dynamic load test results gathered in the blind experiment from the static values of up to 20% in most cases, sometimes even up to 30%. This can be related to the known soil inhomogeneities, interpretation and modelling in CAPWAP and method inherent uncertainties. In cases where the static values were known by the testers for calibration, the deviations were significantly smaller. It has to be taken into account, that the two static load tests showed different results as well. Due to the low toe resistance, use of a big drop weight (11 tons) and large drop heights most piles suffered from cracking, which was clearly seen in follow up integrity tests and confirmed by excavation. The piles are available for further research.

Introduction

Bored piles are used in many construction projects of the German waterways authorities, e. g. bridges, piers or locks. Their load carrying capacity varies with pile type and geometry as well as soil type, parameters and structure and is thus not easy to calculate in advance. Dynamic pile testing as a cost effective addition or replacement for expensive load tests is accepted in many places (Beim and Likins 2008) but still doubted in others. Inspired by the international prediction event for piles in residual soil carried out in the frame of ISC'2 (Viana de Fonseca and Santos 2008), governmental research institutes have designed an experiment in a geological setting typical for glacial and post-glacial areas in northern Germany. Some results have already been presented by Niederleithinger et al. (2012), Herten et al. (2013) and Baeßler et al. (2013). It was intended to perform a blind test for load capacity estimation using dynamic pile testing on six drilled shafts involving five test crews. Two other piles would have to be tested thereafter using static and dynamic methods.

For this purpose a proper site had to be selected and characterized in a manner that comparable boundary conditions are guaranteed for all tests. Limitations in terms of testing equipment, time and budget had to be met. Thus an intensive geotechnical and geophysical investigation program had to be carried out.

Site characterization

All experiments were performed at the BAM Test Site Technical Safety, north of the village Horstwalde about 60 km south of Berlin, Germany. Explosives certification, safety containments drop test up to 200 tons as well as large fire experiments are performed here (BAM 2011). The site includes a Non-Destructive-Testing (NDT) test and validation facility for various investigation purposes and techniques (Niederleithinger et al. 2009).

A part of the site was selected and dedicated to the tasks of this study. It underwent a detailed site investigation using boreholes, cone penetration tests (CPT), as well as geophysical investigation. More details are given in (Niederleithinger et al. 2012). Figure 1 shows the conceptual layout of piles and investigation points.

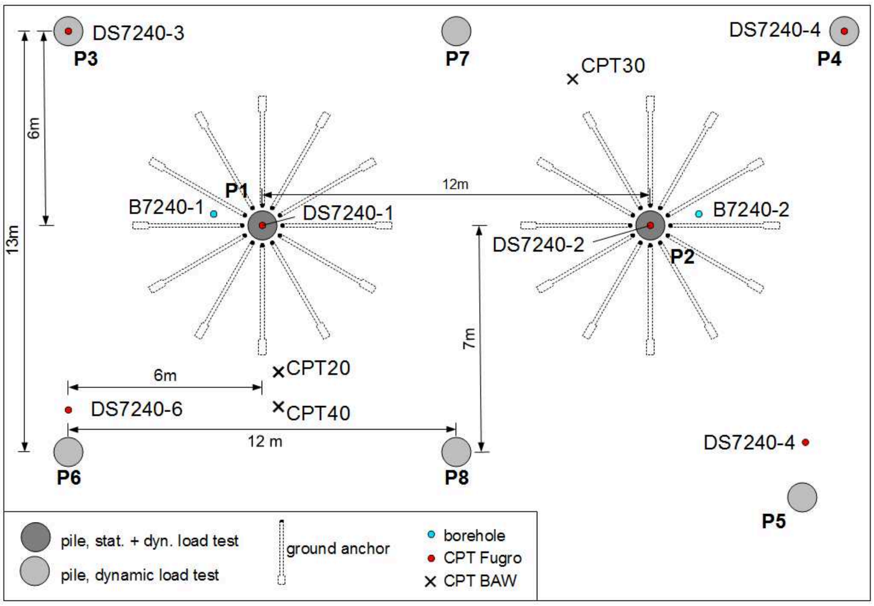

Figure 1: Layout of piles and site characterization

The soil profiles of both the two boreholes (Figure 2) don't show significant differences, sands of medium grain size dominating. However, grain size analysis has shown much more coarse material in the western borehole (B7240-2) in depths of more than 15 m, compared to B7240-1. CPT results confirmed this result, showing tip resistances up to 20 MN/m² in the west and mostly around 5 MN/m² in the east. To assure comparability in toe resistances of all piles, length was limited to 10 m. Thus we had to take into account that the load capacity would probably be dominated by skin friction.

Piles

Eight drilled shafts (P1-P8, Figure 1) have been constructed at the test site. The minimum distance between piles is more than 8 m to avoid any mutual influence by piling, anchoring or testing. Pile length is 10 m below surface and a diameter of 0.9 m in general. For P3 to P8 a 1 m cap was cast on top (made from same concrete batch) and a 1.2 m steel casing added for dynamic testing. P1 and P2 have 0.5 m load cell setup at the toe and a 0.5 m cap plus 0.7 m casing (Figure 4).

The piles have been constructed by Bauer AG. Various measures for quality assurance and control have been taken, e.g. verticality measurements, use of a textile liner for toe shape control and integrity tests. Concrete samples have been taken and used for various lab tests, as compressive strength (> 70 MPa on average after 91 days), static and dynamic Young's modulus (on average 36100 MPa and 35200 MPa after 91 days, respectively) and tensile strength (4.7 MPa after 28 days).

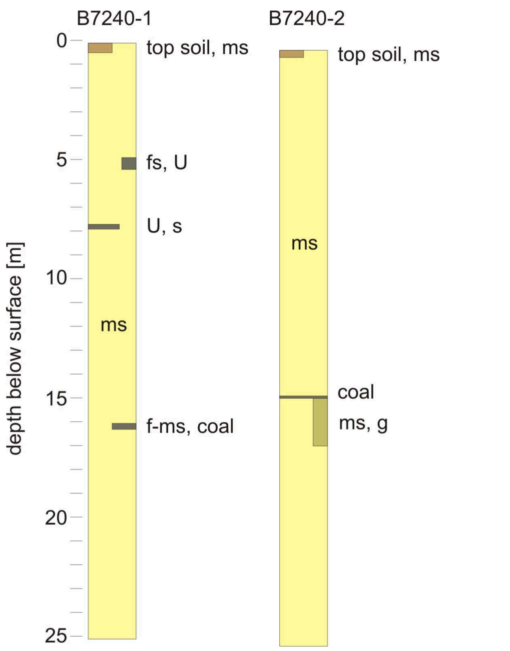

Figure 2: Soil profile of boreholes B7240-1 and B7240-2. Main material is ms-fs, mixed with varying content of silt, coal, and gravel.

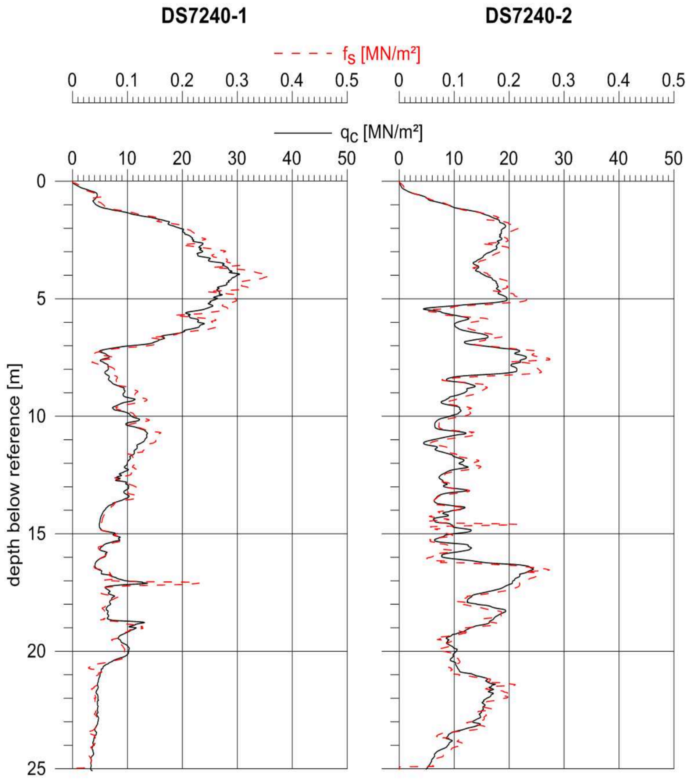

Figure 3: Selected CPT results. q_c: cone resistance (solid line), f_s: skin friction (dashed line).

Static load tests

The static load tests have been designed and performed according to the German Recommendations on Piling (DGGT 2013). For the static tests a loading platform on top of the hydraulic jack was used, which transferred the load via 12 anchors in 14.5 to 20.5 m depth (Figure 4). The anchors have been installed after pile construction. Piles were equipped with load cells on top and at toe level as well as vibrating wire and fiber optic strain sensors at three levels (Figure 4, Figure 5). Additional ultrasonic sensors were accidentally damaged during construction. The static load tests (Figure 6) have been performed by Bauer AG.

For pile P1 the settlement criterion (10% of diameter) as a measure for pile capacity was reached at 2900 kN (1900 kN skin friction, 1000 kN toe resistance). It has to be noted, that significant creep was observed after 2626 kN in the first load cycle. So this value is used for total resistance in the reminder of the study. The load regime for pile P2 has been changed thereafter (smaller load steps). At a maximum load of 3200 kN again significant creep was observed (k_s = 2.2 mm). The test was stopped here at a total settlement of 35 mm to allow optional re-testing. Skin friction was determined to be 2.576 kN, toe resistance 627 kN.

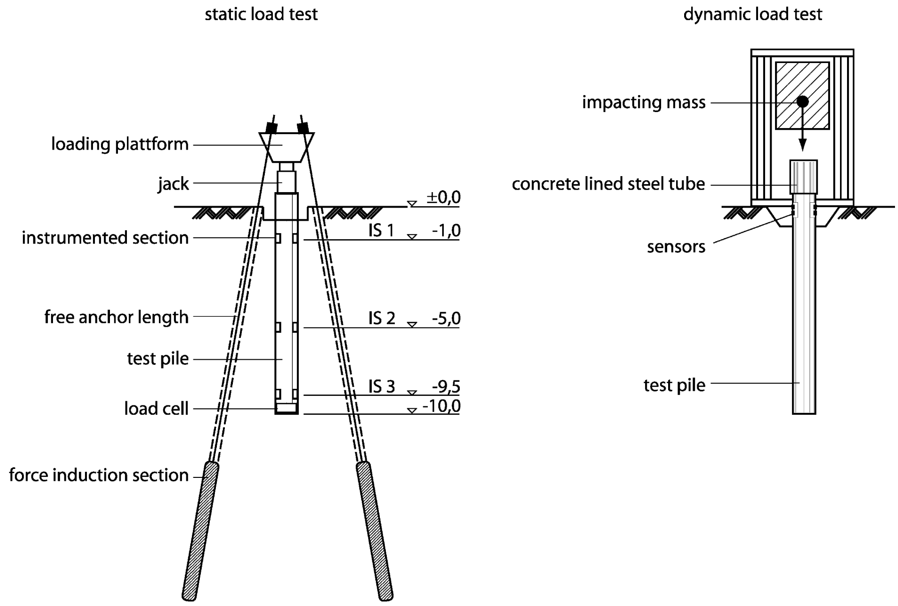

Figure 4: Setup of static (P1, P2), left) and dynamic load tests (P3-P8).

Figure 5: Reinforcement cages of piles P1 and P2 with instrumentation. Toe load cells and various strain gage, fiber-optic and ultrasonic sensors can be seen on the left.

Dynamic load tests

Dynamic load tests have been performed by five independent test crews. Each crew tested a virgin pile and re-tested one or more additional piles. They have used the same drop weight of 11 t (Figure 6), but have been requested to bring their own instrumentation. The crews used two or four sets of strain sensors and accelerometers and were allowed to set up their own schedule (number and height of weight drops). However, they were asked to work according to the German Recommendations on Piling (EA Pfähle). All crews used equipment of PDI, Inc. Data evaluation and interpretation was made by the CAPWAP method. This method uses a simplified 1-D model of pile and subsurface and an inversion strategy to fit the data. Results are values for skin friction and toe resistance. Even a simulated static load test curve (neglecting creep) can be calculated. It has been seen that there is room for interpretation, as some parameters have to be set by experience and data may contain errors or effects not taken into account by the model. Again, all consultants used the same software (PDI Inc.).

Tests on P4 to P8 were made as blind tests. Static load test were performed after all consultants have delivered their results. P1 and P2 were dynamically tested after they have been statically loaded at the same point in time as P3, all by the same consultant and after the results of the static load test have been known.

Figure 6: Static and dynamic load test setup at BAM-TTS.

Figure 7 shows the result of the static and dynamic load tests (on virgin piles) compared to the expected resistances calculated according to the German Recommendations on Piling (EA Pfähle, DGGT 2013) separately for all piles using the nearest CPT. In general, all values are much lower than the average load resistance according to EA Pfähle (50% values in Figure 7), which emphasizes the benefit of any kind of testing in general. However, they are in the same order of magnitude as the lower 10% percentile. The dynamic load test results in the blind test show significant scatter, which only partly can be explained by subsurface inhomogeneities or differences between piles (note difference between both static load tests). Figure 8 shows also the results of re-tests for all piles. Symbols represent different test crews. There seems to be a bias between different interpreters. The ratio between skin friction and toe resistance varied as well between consultants.

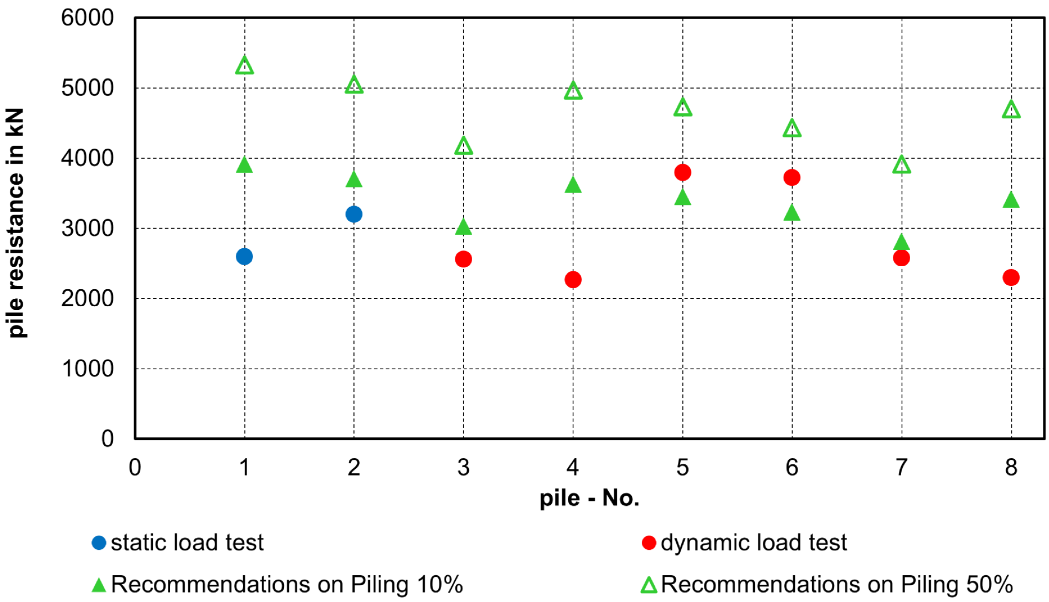

Figure 7: Result of static and dynamic load tests (blind test) in comparison to values expected after EA Pfähle (DGGT, 2013).

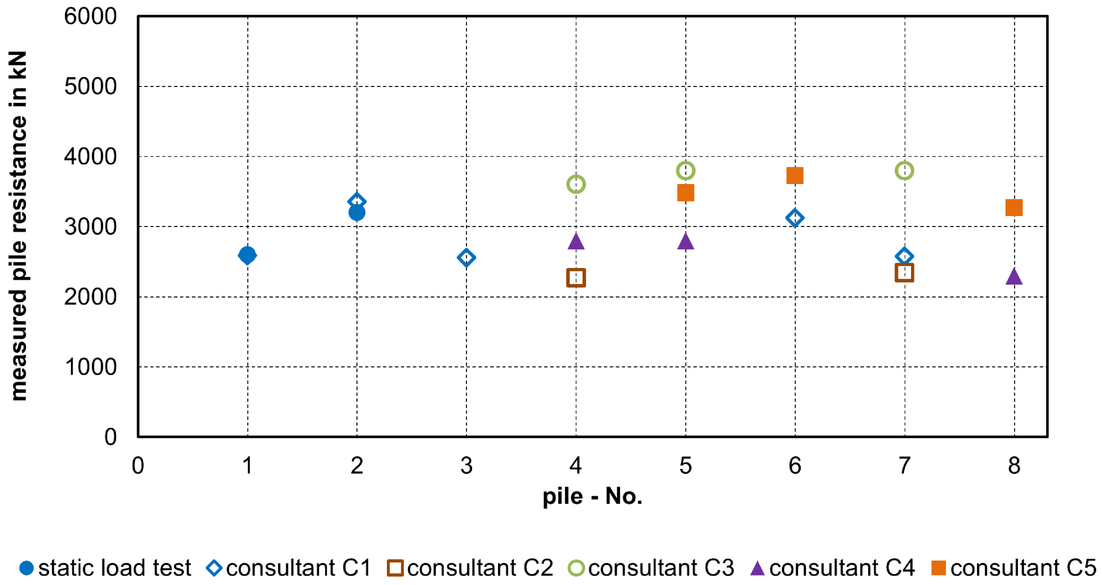

Figure 8: Result of static and dynamic load tests (blind test, except for piles 1 to 3) for the five test crews. For pile 1, static and dynamic results are coincident.

Results from additional instrumentation

The fiber optic sensors in Pile P2 delivered valuable insight. We have to be able to back-check the values measured by the toe load cell, which have been under discussion at a certain point of the investigation. Newly developed, very fast sensors helped in the interpretation of integrity tests. Details are given in Schilder et al. (2013).

Several pore pressure transducers have been placed in the subsurface prior to the test, most of them close to Piles P1 and P2. While during pile construction and anchoring pore pressures have shown only minor pressure changes (never exceeding 50 hPa compared to background pore pressure of 1450 hPa, measured close to anchors), there were significant changes during dynamic load test. The amplitude was proportional to drop height and reached maximum amplitudes of 400 hPa close to pile toe (background value 630 hPa). Data have not been fully evaluated yet.

Integrity

All piles have been checked for integrity before and after the static/dynamic load tests using the low strain integrity testing method according to EA Pfähle (DGGT, 2013). Most test crews did additional integrity checks in between and remarked that the piles have been probably damaged after the first drop weight blows. Figure 9 and Figure 10 show the integrity test results for pile P7. The signal before load tests (Figure 9) shows a clear toe reflection at the expected position and only a very minor impedance change close to the top (probably due to the steel casing). After the load tests the signal now exhibits a strong reflection at an estimated depth of 3.8 m and no significant toe echo.

In by far the most cases, piles are not damaged significantly by dynamic load tests. However in this study we have used quite large drop heights (about 1 m in some cases) and a large number of blows (more than 10 in some cases). In addition, the toe resistance of the piles is due to soil conditions comparably weak. This resulted in settlements per blow (max. 30 mm) above the recommended limits (3 to 5 mm). The consultants have been free in parameters choice and have known that these piles will not be used after the tests. Most of the (compressive) stress wave induced by the weight drop is reflected at the toe as tension, which might lead to tension cracks at a point which is determined by geometry and material parameters. To validate this hypothesis we have excavated two piles (P4 and P7) up to a depth of 4 m below surface. Figure 11 shows the excavated pile P7 with cracks at exactly the position estimated by the integrity test. Results for P4 have been similar, but cracks were closer to the pile top. The cracks have probably appeared just after the first blows. Thus this may have influenced at least the test results achieved at a later point. This effect cannot be quantified, but has made the data evaluation for the test crews at least more difficult.

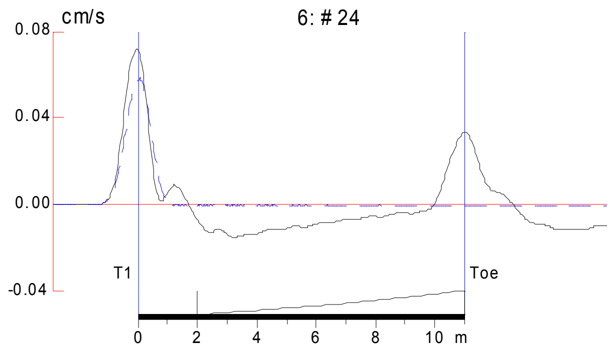

Figure 9: Pile P7: Integrity test signal before dynamic load tests.

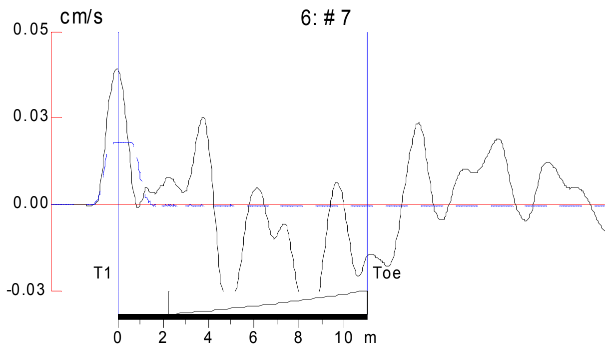

Figure 10: Pile P7: Integrity test signal after dynamic load tests.

Figure 11: Pile P7: Left: excavated pile. Top. Cracks at 3.75 m depth below top of pile.

Summary and conclusions

We have performed a round robin test involving dynamic load tests performed by five test crews on bored concrete piles in glacial soil. Boundary conditions have been difficult as the subsoil was not fully homogeneous and the piles have only minor toe resistance. Most piles have been damaged by the tests, causing difficulties in data interpretation.

All consultants have shown that the pile resistances are close to the lower 10 % percentile of the values expected by the German Recommendations for Pile Testing (DGGT, 2013). Significant deviations from the expected values have occurred in the static as well the dynamic load tests. Insofar the study has proven the importance of any load test.

The comparison of the resistance values determined by the individual consultants showed significant deviations between the lowest and highest results. The reason seems to lie in an individual bias imposed by the consultants. The deviations have been up to 30% for a single pile, which has not been fully evaluated yet. The results of each consultant for different piles are much more consistent and can be mainly explained by varying site conditions.

It has to be stated clearly, that all results refer to bored piles and specific site conditions only. Any deviations in test results cannot be transferred to other pile systems.

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