Foundation Rehabilitation of Bridge over Danube: the Role of Pile Integrity Testing

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FOUNDATION REHABILITATION OF BRIDGE OVER DANUBE: THE ROLE OF PILE INTEGRITY TESTING

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ABSTRACT

The construction of the bridge near Pöchlarn over Danube, in Austria was begun 1998 and completed in 2002. The four middle piers of the bridge consist of sink caissons made of pre-cast reinforced concrete elements. Each caisson is founded on 18 bored piles of 1.2 m diameter. In a first step, two pilot piles of about 40 m length are installed for each caisson. After the pilot piles were completed, an accident happened in April 1999. A cargo ship collided with the pier no 3 and damaged the two pilot piles. Since the piles were below water level, it was very difficult to inspect the damage. Therefore, integrity tests were carried out to know the level of damage. The possible scenarios range from local repair to installation of new pilot piles. The paper describes a case study of the repair works of the damaged piles, where under water pile integrity tests were carried out.

INTRODUCTION

The behaviour of foundation piles is affected by several factors, which are difficult to quantify, such as the installation method (drilling, casing, supporting), the installation speed and the workmanship. As a consequence, the bearing capacity of foundation piles is usually determined by static load testing. However, this destructive method is expensive and time-consuming. Therefore, the number of static load tests per site is rather limited.

There are several non-destructive pile testing methods based on small strain impulse techniques which enable to know the integrity of all piles on a site. The sonic integrity test (SIT) of foundation piles has been established as a standard method for quality control for bored piles and drilled shafts. The integrity test is a non-destructive method and can highlight anomalies such as major cracks, necking, soil inclusions or voids, which may have negative impact on the deformation and strength behaviour of the piles. The pile integrity testing is an economical way of the quality control of piles whether it is pre-cast or cast in-situ piles. Optimal pile design can be achieved by combining the static load tests with the integrity tests.

The integrity tests are usually carried out after the installation of the piles and before the construction of the superstructure. Sometimes, the integrity tests are also performed on piles under existing structures to assess the safety level. In this paper, a case study is described where the integrity tests were carried out under water. The tests were carried out on the foundation piles of a bridge pier, which were damaged during an accident with a cargo ship. The tests served two purposes. First, it was not clear whether the damage was limited to the upper part of the piles or along the entire pile length. In the former case, the piles can be repaired, while in the latter case the damaged piles had to be discarded and replaced by new ones. A repair of the piles is of course more economical. Second, the tests were used to check the integrity of the repaired piles.

Project Description

The construction of the bridge near Pöchlarn over Danube in Austria was begun 1998 and completed in 2002. The bridge is a cantilever bridge made of hollow box of reinforced concrete. The bridge has a total length of about 460 m, which consists of three middle spans of each 105 m and two spans to the ramps of each 72.5 m. The four middle piers consist of sink caissons made of three pieces pre-cast reinforced concrete oval shape elements. Each caisson is founded on 18 bored piles of 1.2 m diameter. In a first step, two pilot piles of about 40 m length are installed for each caisson. These two pilot piles provide some guide for caisson sinking. Afterwards the caisson is sunk and the rest 16 piles are installed in the foundation box (see Fig. 1).

After the pilot piles were completed, an accident happened in April 1999. A cargo ship collided with the pier no. 3 and damaged the two pilot piles. The both pilot piles were broken at the level of about 1 m above river bed (see sketch in Fig.2).

Since the piles were below water level, it was very difficult to inspect the damage.

In addition, the drilling and excavation at the site was very difficult due to presence of Melk sand. The Melk sand is typical geological formation for this region. The Melk sand is pre-compressed sand from the ice age, which is very hard to excavate. The sand is composed of very sharp quartz crystals. This unpleasant characteristic led too high wearing of drilling tools. Due to the presence of Melk sand there is high risk of liquefaction. The possible scenarios range from local repair to installation of new pilot piles. In order to make an objective decision on the construction alternative, low strain pile integrity tests were carried out.

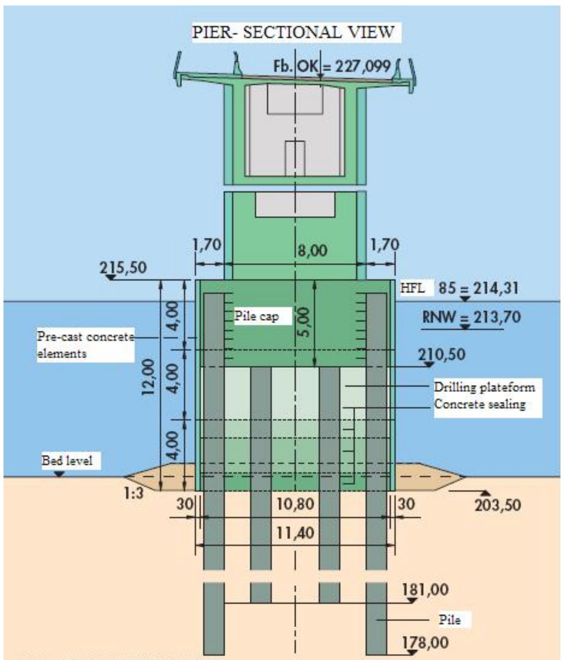

Fig. 1: The sectional view of the pier

PILE INTEGRITY TEST

A pile integrity test (also known as sonic integrity test or low strain integrity test) is one of the methods for assessing the condition of piles or shafts. It is cost effective and fast. The test is based on wave propagation theory. The name "low strain test" stems from the fact that when an impact is applied to a pile it produces a low strain. The impact produces a compression wave that travels down the pile at a constant wave speed and is reflected at the pile toe. If there are changes in cross sectional area (such as a reduction in diameter) or material (such as a void in concrete) also produce wave reflections. The reflected signals are amplified, filtered and then interpreted based on the theory of wave transmissions which provides the indications of imperfections in piles.

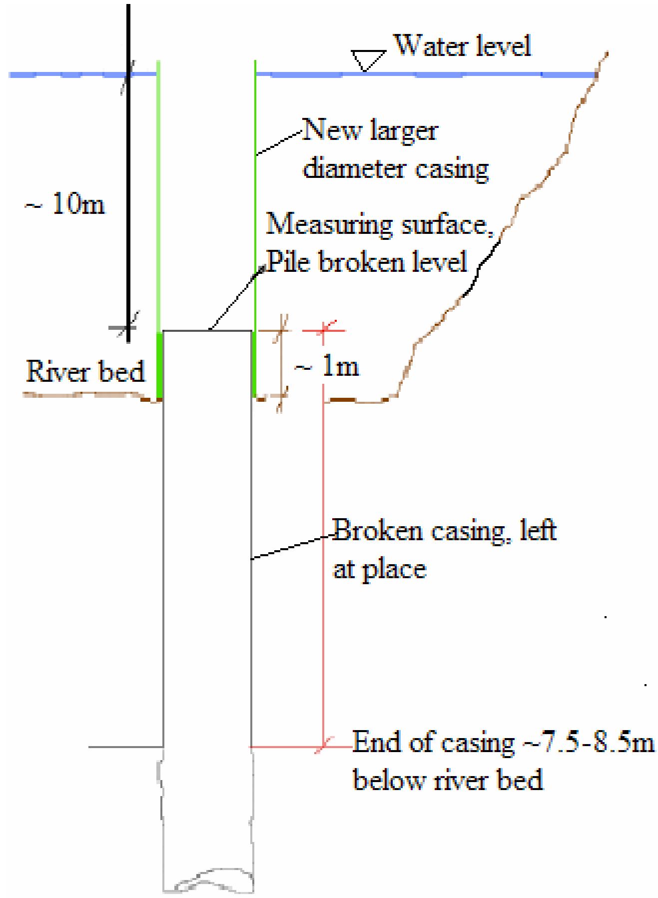

Fig. 2: Sketch showing the pile length and damage level

The SIT test is performed with a hand held hammer (Fig. 3) to generate an impact. An accelerometer or geophone is placed on top of the pile to be tested to measure the response to the hammer impact and a data acquisition and interpretation electronic instrument is attached to the computer. The test works well in concrete or timber foundations that are not excessively slender.

As a rule the test should be carried out on the pile top surface, free of dirt and cracks. But in our case the pile top surface was under water and there was no possibility of physical inspection. Moreover, there was a problem to generate the sonic impulse into the body of pile. It is relatively difficult to control the hammer blow under the water, which was still more difficult in flowing water. In addition, the water film on the pile top substantially reduces the blow energy, which means, a strong blow is needed to generate the required intensity of the sonic impulses.

The test was carried out using the TNO FPDS SIT 3 and TNO FPDS SIT 5 sonic impulse measuring devices developed by Foundation Pile Diagnostic System (FPDS), in Netherlands. The equipment used for SIT is robust and portable and comprises a light-weight field computer, transducer, connecting cables and a plastic mallet.

Fig. 3: Wave generation with the help of a hammer

The pile integration testing was started on 30.04.1999 and the last test was conducted on 30.07.1999, after the completion of repair works. The tests were conducted on pilot piles number 3 and 9, in three stages; before repair of pile heads, after repair of pile heads and after repair of all damages. The summary of tests is presented in table 1.

Table 1: Pile integrity test schedule

Test date	Pile No.	Measured points	Recorded signals	Age of concrete (weeks)
30.04.1999	3, 9	15	117	3
25.06.1999	3, 9	6	18	11
01.07.1999	3, 9	4	12	12
13.07.1999	3, 9	14	40	14
30.07.1999	3, 9	2	6	17

The test was carried out with the help of a diver, who went into the water and hammered on the pile surface; the reflected wave was measured with a sensor attached to the pile top. First of all, the top surfaces of the damaged piles were cleaned and measuring points were marked (see Fig. 4). Then the impulses were generated with a hammer and the reflected signals were measured. The measurement level was about 9.50 m below the river water level. In addition, for the determination of wave velocity, some tests were carried out on the broken pile pieces. A wave velocity of 4200 m/s was measured for those piles.

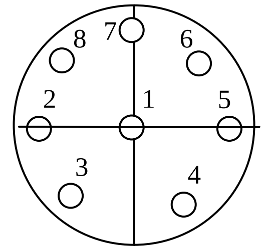

Fig. 4: Marking of measurement points on the top of pile

TEST RESULTS

After the completion of tests, the recorded signals were analysed and interpreted considering only interpretable part of the signals. Figure 5 and the Fig. 6 show some test results of pile no. 3 before and after repair of pile heads. Similarly, the Fig. 7 and Fig. 8 show the results of pile no. 9 before and after the repair of pile heads.

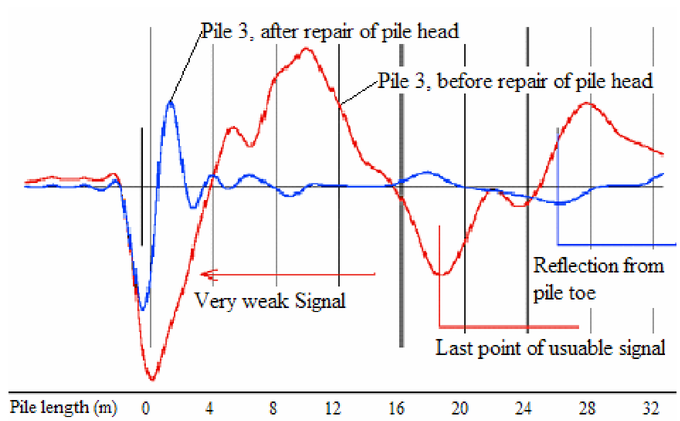

Fig. 5: Test results of the pile no. 3, signal 1

The test results (before repair of pile heads) showed that both piles were damaged near the top surface where the measurements were carried out. There were small cracks and changes in concrete structure. The damage to the structure was only partial. There were no damages below 4 m from the river bed. Due to difficulty in conducting tests under water, and due to damages at the measuring surface (pile heads), the interpretable pile length from the measured signal was only between 16.5 m and 17.5 m, measured from the broken pile level.

The test results of pile no. 3 after the repair of pile head showed a consistency in signal so that the interpretable length of pile was about 26.4 m (from broken level). Negative changes in impedances were not observed. For the length between 6.5 m and 9.0 m from the broken level, a reduction of cross section was observed (Fig. 9). The positive change in impedance at a level of 17.5 m is primarily due to increase in skin friction.

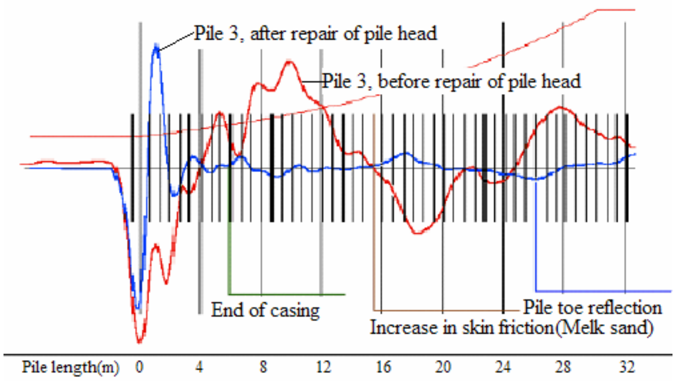

Fig. 6: Test results of the pile no. 3, signal 3

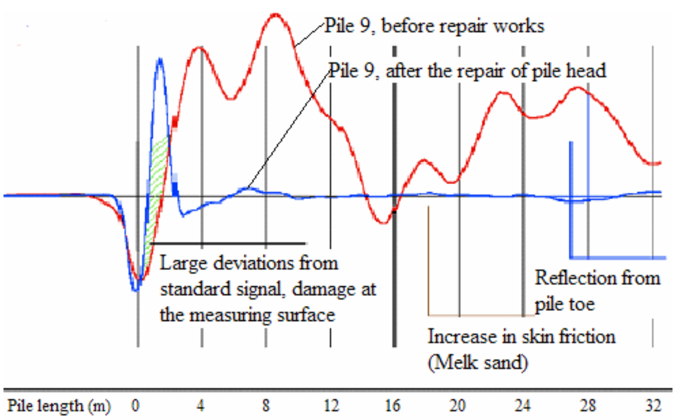

Fig. 7: Test results of the pile no. 9, signal 1

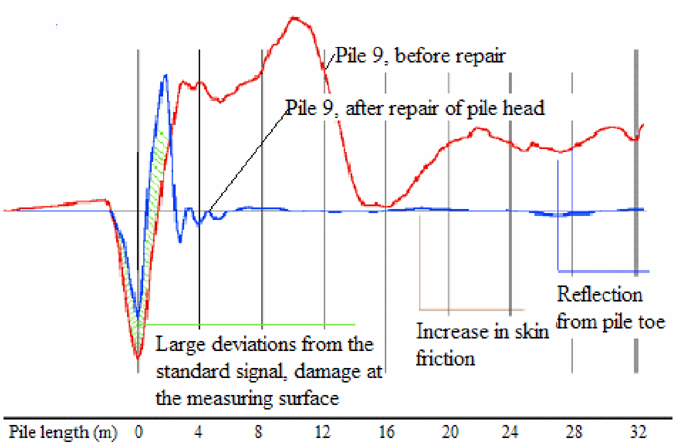

Fig. 8: Test results of the pile no. 9, signal 2

Similarly, the test results of pile no. 9 after the repair of pile head also showed a consistency in signal so that the interpretable length of pile was about 27 m from the pile broken level (Fig. 9). Negative changes in impedances were not observed. For the length between 7 m and 10 m, a reduction of cross section was observed. The positive change in impedance at a level of 18.5 m is primarily due to increase in skin friction. This shows a high level of reliability in both measurements.

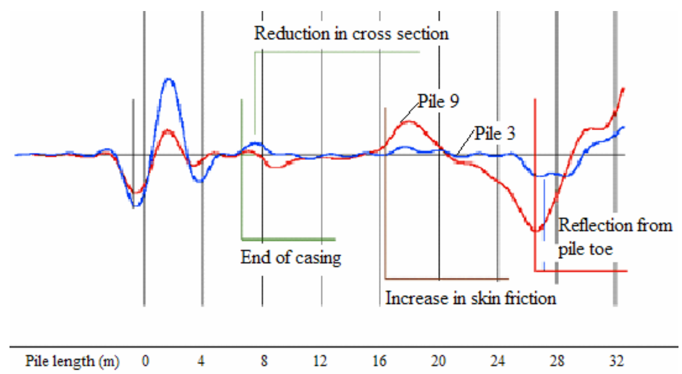

Fig. 9: Test results of piles no. 3 and 9 after the repair of pile heads

Our test showed that the damage was limited to the upper part of the piles. Therefore, the pile repair option was chosen. The repair works of the pilot piles were carried out in two stages. In the first stage, only pile heads were repaired. For this purpose a larger diameter steel casing was placed on the existing pile, the joint was sealed with concrete and the water inside the casing was pumped out. The pile heads were chiselled and cleaned. Then the fresh concreting was placed. After completion of the repair of the pile heads, new integrity tests were carried out.

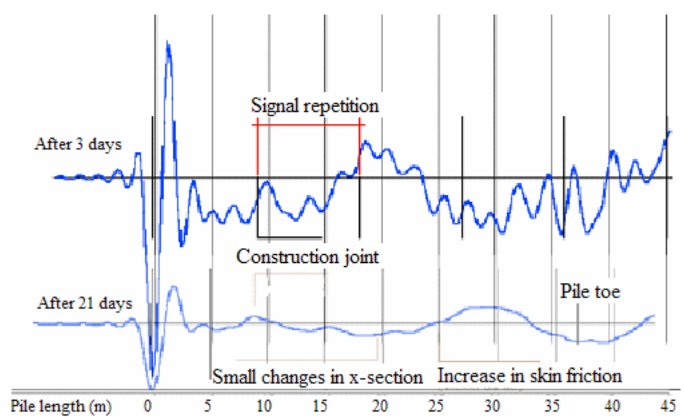

Fig. 10: Test results of pile no. 9 after the repair of piles, after 3 days and 21 days of concreting.

In the second phase of repair works, the broken pilot piles were reconstructed up to their final level above water. For the extension of broken piles, several holes were bored into the existing piles and high strength steel rods (GEWI rods) were inserted into the piles. Then the top surfaces of the broken piles were cleaned and casings were placed in positions. Afterwards, reinforcement cage was placed and concrete was poured into the casing till the final level above water. Then new integrity tests were carried out in 3 days and 21 days after the concreting. The results of last integration tests after the complete rehabilitation of pilot piles are presented in Fig. 10 and Fig. 11.

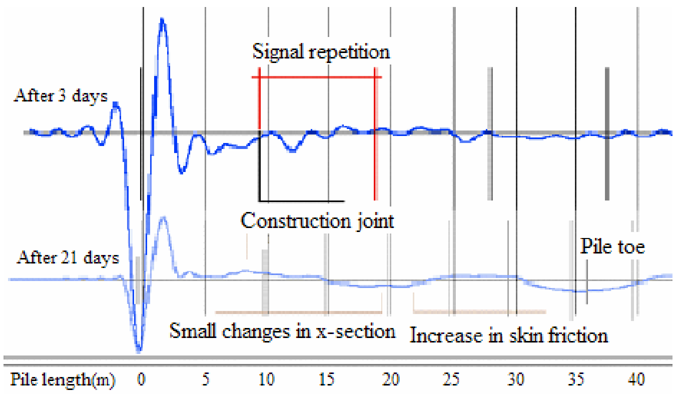

Fig. 11: Test results of pile no. 3 after the repair of piles, after 3 days and 21 days of concreting.

CONCLUSION

The first phase pile integrity tests showed that the damage was limited to the location immediately over the river bed. Although the test were carried out under water, there was no large deviations on the recorded signals due to the presence of water and dirt except the deviations due to damage of measuring surfaces (pile heads).

The results of the second phase tests (after the repair of pile heads) showed some minor changes in cross sections of both piles. The tests after the repair works of whole pile showed a sound integrity of the piles throughout the length. This integrity test guaranteed the quality of repaired piles so that these piles can be used for pier foundations without any limitations.

REFERENCES

ASTM D5882-96, [1996], Standard Test Method for Low Strain Integrity Testing of Pile, American Society for Testing and Materials.

Ludwig, J., [1999] “Österreich erste Unterwasser-Pfahl-Integritätsprüfung” , A report on pile integrity testing at Danube bridge, Pöchlarn, Austria.

Middendorp, P., Reiding, F.J., [1988], Determination of Discontinuities in Piles by TNO Integrity and Signal Matching Techniques, 3rd International Conference on The Application of Stress Wave Theory on Piles, Ottawa, Canada.

Van Koten, H., [1997], “The Determination of the Form and Size of Discontinuities in Foundation Piles by Means of Sonic Testing”, TNO Delft.

Wasitzka, E., [2001], A report on the construction of Danube bridge at Pöchlarn, Austria in “PORR Nachrichten Nr. 136”, PORR- company news letter.