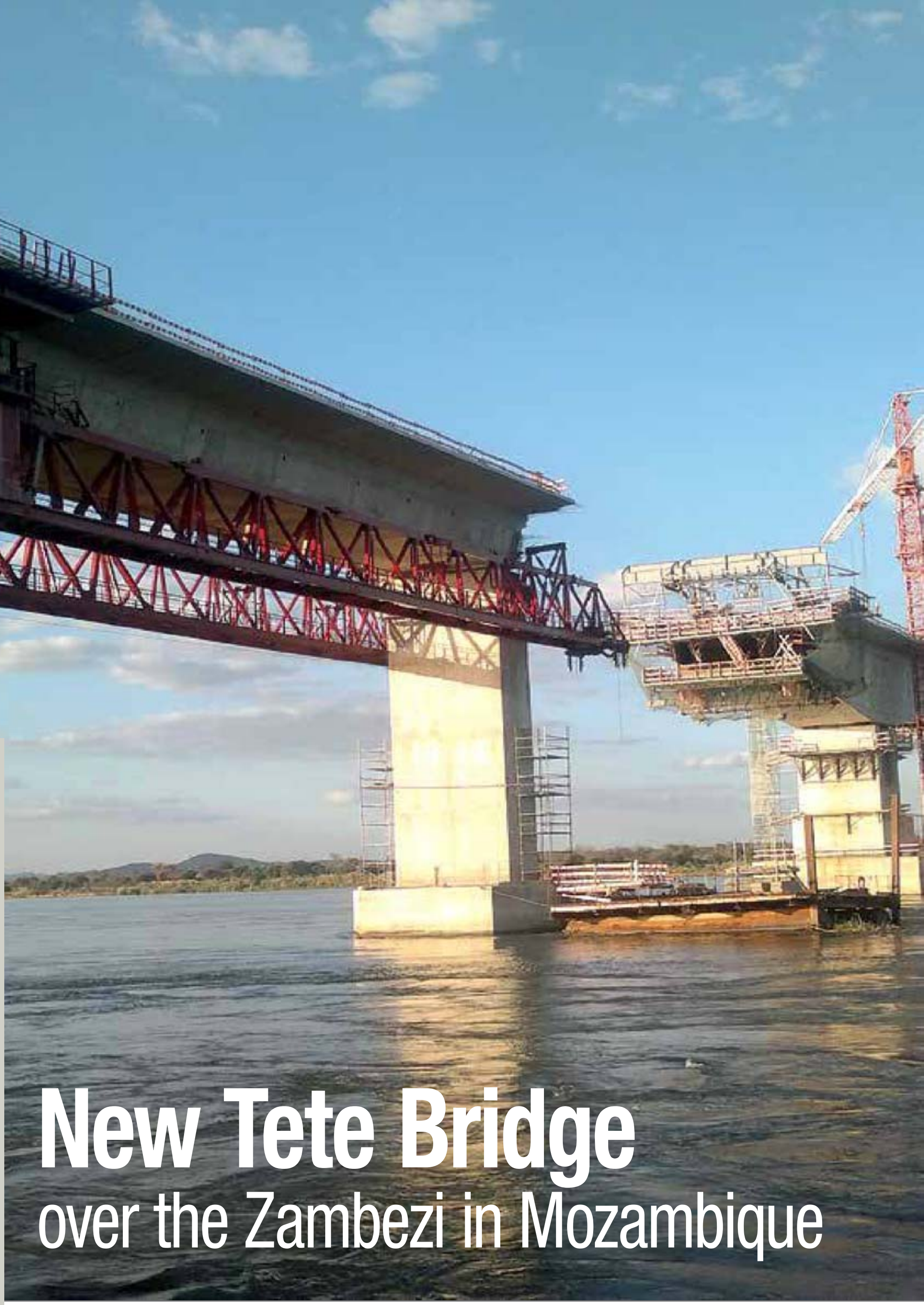

New Tete Bridge
over the Zambezi in Mozambique

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INTRODUCTION

Quality control of foundation plays an important role in achieving a reliable deep foundation element. Currently, the most commonly used methods of foundation integrity verification are indirect tests involving acoustic wave propagation, such as the Pulse Echo Method (Pile Integrity Testing or PIT) and Cross-hole Sonic Logging (CSL). More recently, Thermal Integrity Profiling (TIP) has been garnering significant attention from foundation engineering professionals.

This article describes the use of CSL during the construction of the new Tete Bridge over the Zambezi River in Mozambique (Figure 1). CSL identified anomalies in two of the piles tested, PP1A and PP1D. These anomalies were evaluated to determine their depth, size and extent relative to the cross-section of the piles. Core samples were later obtained to confirm the existence of defects, and corrective action was taken.

The construction of the new Tete Bridge started in April 2011, and opening to traffic is scheduled for October 2014.

Figure 1: New Tete Bridge under construction over the Zambezi River in Mozambique

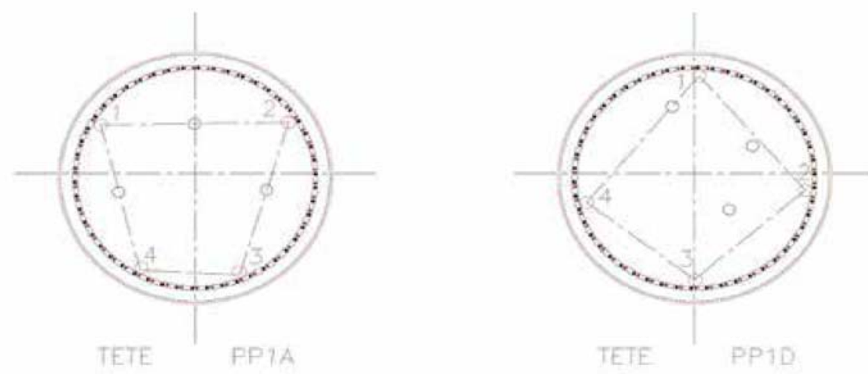

Figure 2: Shaft schematic PP1A and PP1D

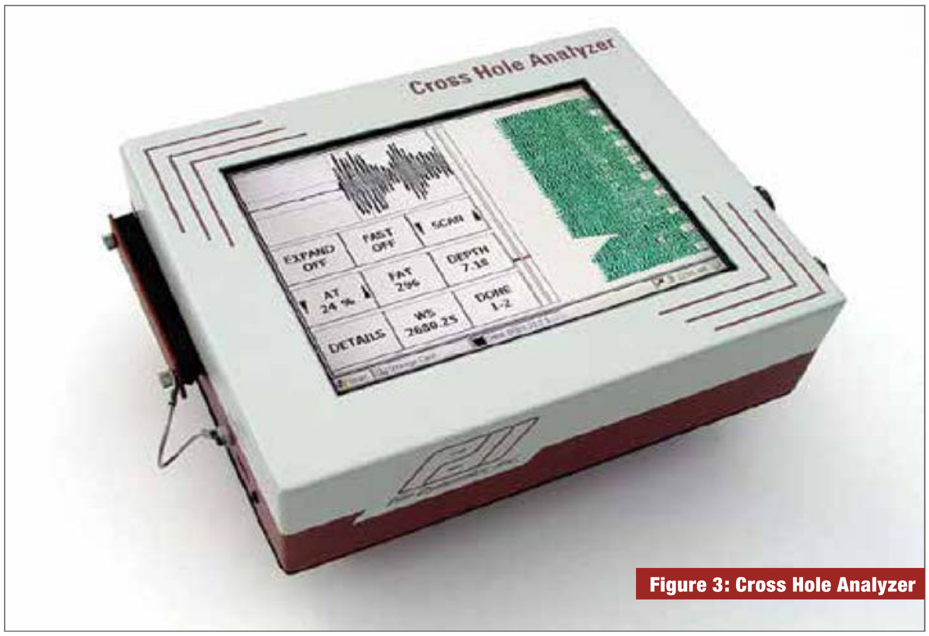

Figure 3: Cross Hole Analyzer

Table 1 Evaluation of shaft integrity based on FAT and energy reduction

Evaluation	FAT increase		Energy / signal strenght reduction
Good quality	0 to 10%	and	< 6 dB
Questionable	11 to 20%	and	6 to 9 dB
Poor quality / flaw	21 to 30%	or	9 to 12 dB
Poor quality / defect	> 30%	or	> 12 dB

The bridge is 1,6 km long and will connect the Mpeáduè neighbourhood, in the Tete Municipality, with the locality of Benga in the Moatize District. According to the spokesperson of the Mozambique Council of Ministers, the bridge will boost the development of the Tete Province, ease congestion and give the landlocked countries of Malawi, Zimbabwe and Zambia a route to the Mozambican ports.

METHODOLOGY

Cross-hole sonic logging was performed through four hollow tubes previously installed on the reinforcement of the piles. CSL involves inserting a sonic wave transmitter in a tube and a receiver in another one. The use of four tubes allows six CSL tube combinations (called profiles) for each structural element (Figure 2).

CSL tests were carried out with a Cross Hole Analyzer from Pile Dynamics Inc (Figure 3), in accordance with the procedures described in the standard ASTM D-6760.

Wave travel times from transmitter to receiver through the concrete of the shaft are related to shaft quality – waves that arrive at the receiver later than expected may be indicative of a defect. Similarly, the arrival of waves of lower energy than expected at the receiver may also be reason for concern.

CSL data was interpreted based on first arrival time values (FAT) and energy losses. FAT is the time that the sonic wave takes to travel between each pair of tubes. Wave speed is then calculated by dividing the distance between each pair of tubes by FAT. A decrease in the amplitude of received signal indicates an interruption in

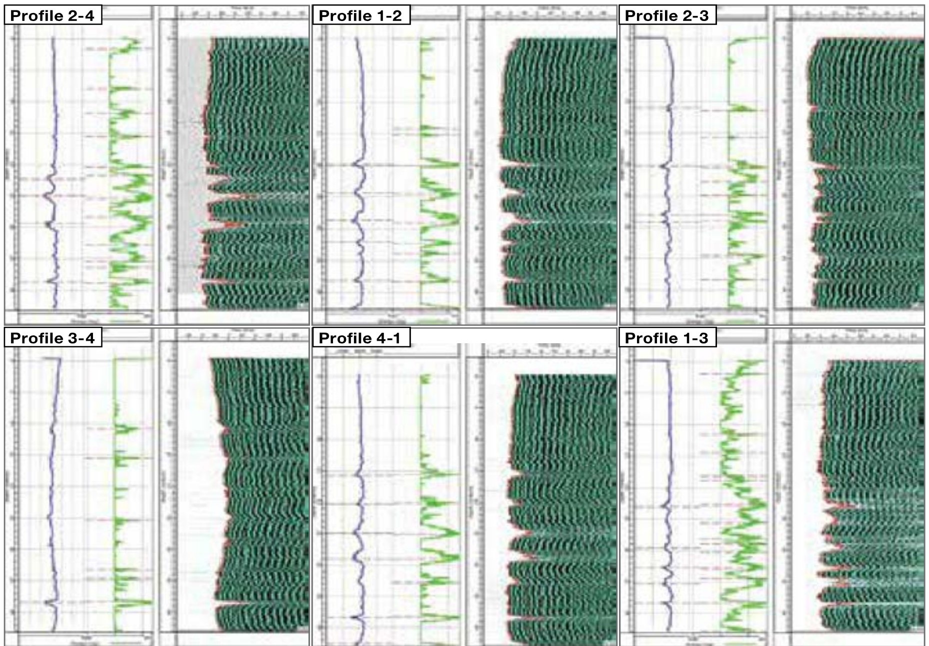

Figure 4: Profiles for shaft PP1A

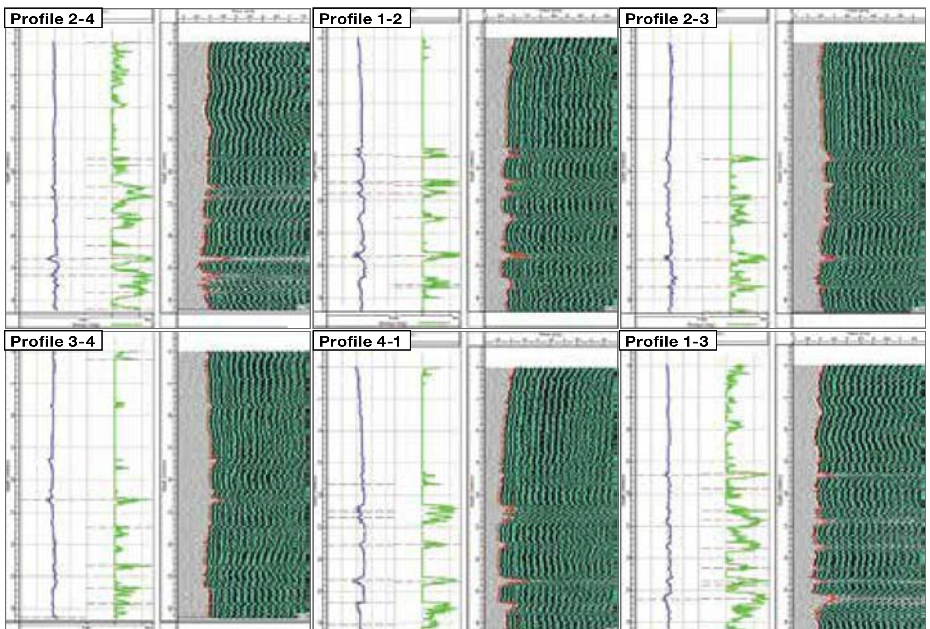

Figure 5: Profiles for shaft PP1D

wave travel, or wave transmission through contaminated concrete.

After obtaining the FAT profile and signal energy losses along the entire pile length, the shafts may be evaluated based on Table 1 (from Likins *et al* 2007).

RESULTS AND INTERPRETATION

CSL results revealed anomalies on piles PP1A and PP1D, as evidenced by Figures 4 and 5, which show significant energy and FAT decreases represented both on the processed results (left side) and waterfall diagrams (right side). All six profiles (pairs of tubes) are shown for each one of the shafts.

Figure 6 represents the cross-section of the shafts at various depths, with anomalous areas shown in gray. Flaws or defects were observed in multiple profiles at each of the depths, in some cases in as many as four of the six tube combinations, indicating defect magnitudes from a quarter to half of the cross-sectional area (note PP1A between 21 and 31 m and PP1D between 16,5 and 40 m). At some depths, anomalies were shown in all profiles at a given depth (PP1A between 37 and 40 m and PP1D between 32,5 and 35 m), indicating that the entire cross-section of the pile at that depth is defective.

INTERVENTION

Coring was performed on both piles, with two objectives:

1. To confirm the anomalies detected through cross-hole sonic logging and determine if they were caused by poor or insufficient grout, or by a fracture or void due to the absence of concrete, or soil intrusion.
2. To enable access to anomalous zones for grout injection and sealing of the voids.

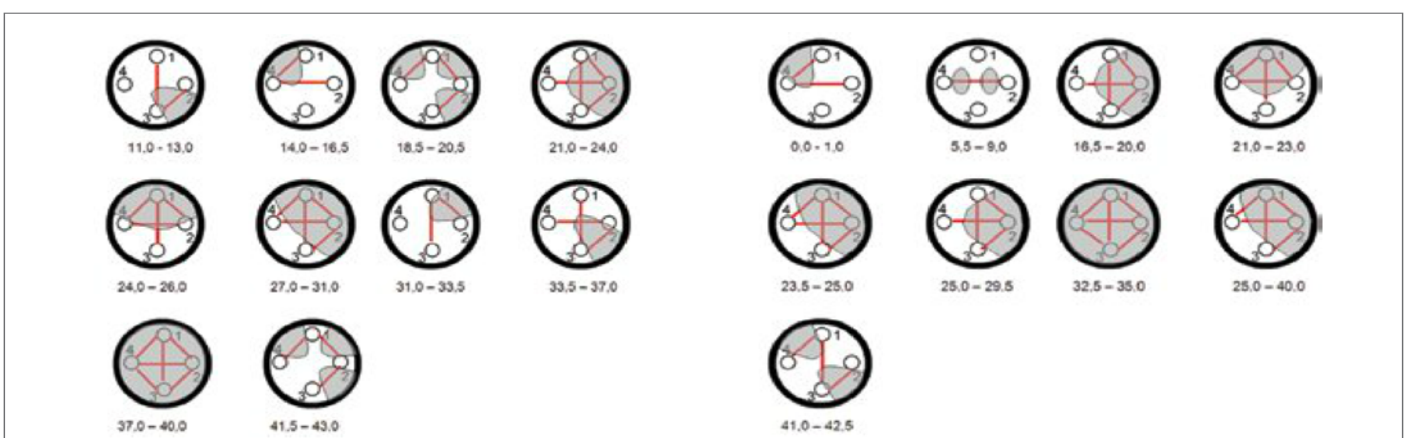

Figure 6: Areas of anomalies identified in piles PP1A (left group) and PP1D (right group)

The core samples (Figures 7 and 8) permitted observation of the composition of the pile material and confirmed the anomalies indicated by CSL. The anomalies were generally caused by an insufficient amount of grout in the concrete. Once the gravity and location of the defects were confirmed, their repair was undertaken through grout injection. Grout absorption was carefully monitored, as illustrated in Figure 9. The areas of greatest absorption of cement grout appear in red. In general

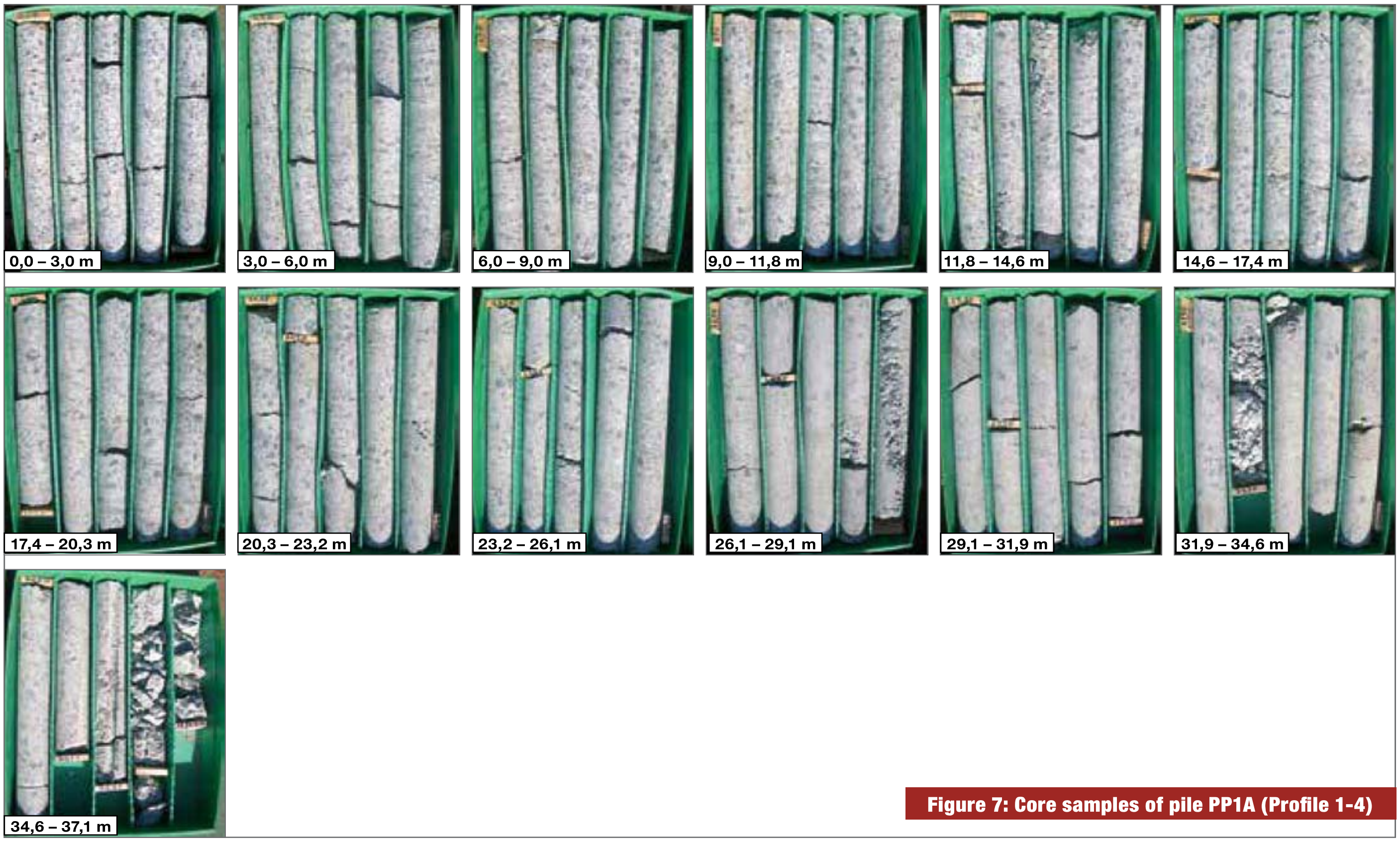

Figure 7: Core samples of pile PP1A (Profile 1-4)

Figure 8: Core samples of pile PP1D (Profile 1-2)

these areas occur at depths below 15 m, corresponding to the depths identified by CSL and shown in Figures 4, 5 and 6.

POST-REPAIR INTEGRITY EVALUATION

After completion of the grout injection process, the integrity of the pilings was once again evaluated by cross-hole sonic logging, in order to verify the result of the repair. Figure 10 shows defects in red, flaws in orange and questionable areas in yellow. The results show significant and widespread improvements in both piles, although indications of defects remained in a few of the profiles. Pile PP1D presented satisfactory results along the entire shaft, with the exception of a location at 33 m depth where values of FAT and energy continue to result in a questionable classification according to the criteria of Likins *et al* (2007). Pile PP1A also shows satisfactory results along the entire shaft, with the exception of a location at 27,5 m depth in profile 1-2, representing a clear improvement in the results. Note that concrete voids filled with grout might have repaired the shaft, but still exhibited slower wave speeds (greater First Arrival Times) than intact concrete, which probably explains most of the yellow "questionable areas" in Figure 10. In addition to the difference in curing time of the newly injected grout, the absence of rock aggregate in the grout results in lower density and resistance, and consequently in a smaller wave propagation speed.

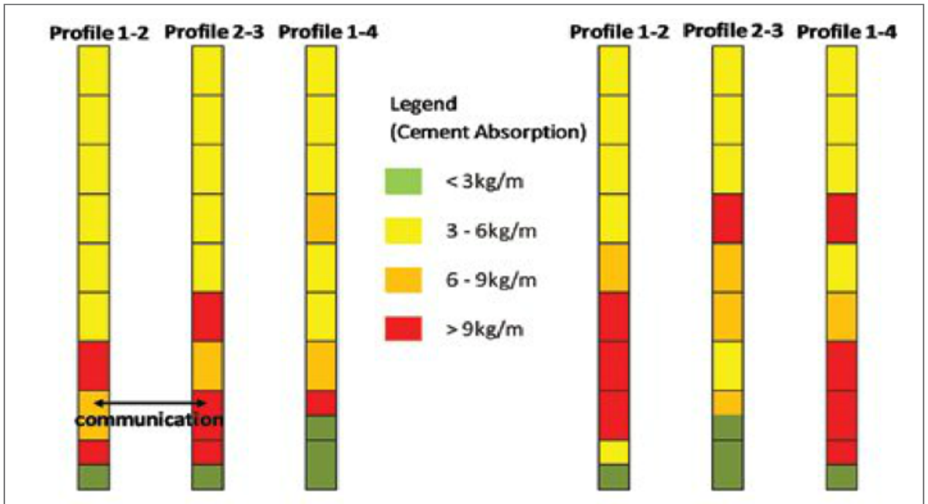

Figure 9: Grout absorption rates for piles PP1A (left) and PP1D (right)

SUMMARY AND DISCUSSION

Currently the most commonly used methods of foundation integrity verification are pulse echo testing (also known as pile integrity testing or PIT) and Cross-hole Sonic Logging, (CSL). Recent developments in integrity testing

Currently the most commonly used methods of foundation integrity verification are pulse echo testing (also known as pile integrity testing or PIT) and Cross-hole Sonic Logging, (CSL). Recent developments in integrity testing technologies include evaluation by thermal methods. Thermal Integrity Profiling (TIP) is an integrity assessment method that relates concrete temperatures measured in a foundation pile during curing with the presence and quality of the concrete

technologies include evaluation by thermal methods. Thermal Integrity Profiling (TIP) is an integrity assessment method that relates concrete temperatures measured in a foundation pile during curing with the presence and quality of the concrete. This type of test is generally conducted within one or two days of pile casting, leading to earlier detection of results. While CSL investigates the portion of the cross-sectional area contained within the access tubes used for the test, TIP may assess the entire cross-sectional area.

As with CSL, TIP requires planning prior to construction to allow measurements to be taken. The decision to conduct pulse-echo tests to verify integrity, on the other hand, may be performed *a posteriori*. Each test has advantages and drawbacks, and should be considered in an overall programme of quality control.

On the new Tete Bridge the integrity evaluation programme included solely cross-hole sonic logging. CSL accurately revealed defects on two foundation piles; these defects were later confirmed by coring. Coring not only allowed for verification of CSL results, but provided access for shaft repair by grout injection. A second programme of CSL testing was conducted after shaft repair, showing that most defects had been corrected.

REFERENCES:

Cruz, J *et al* June 2013. *Control de calidad y reparación de estructuras de fundación mediante ensayos no destructivos (NDT) en el nuevo Puente de Téte, Mozambique*. Presented at the International Conference of Hydraulics and Geotechnics: Lima, Peru.

Likins, G E *et al* February 2007. *Defect Analysis for CSL Testing*. Geotechnical Special Publication No 158, Contemporary Issues in Deep Foundations. *Proceedings* from Geo-Denver 2007 New Peaks in Geotechnics: Denver, CO, USA. (CD-ROM) ◻

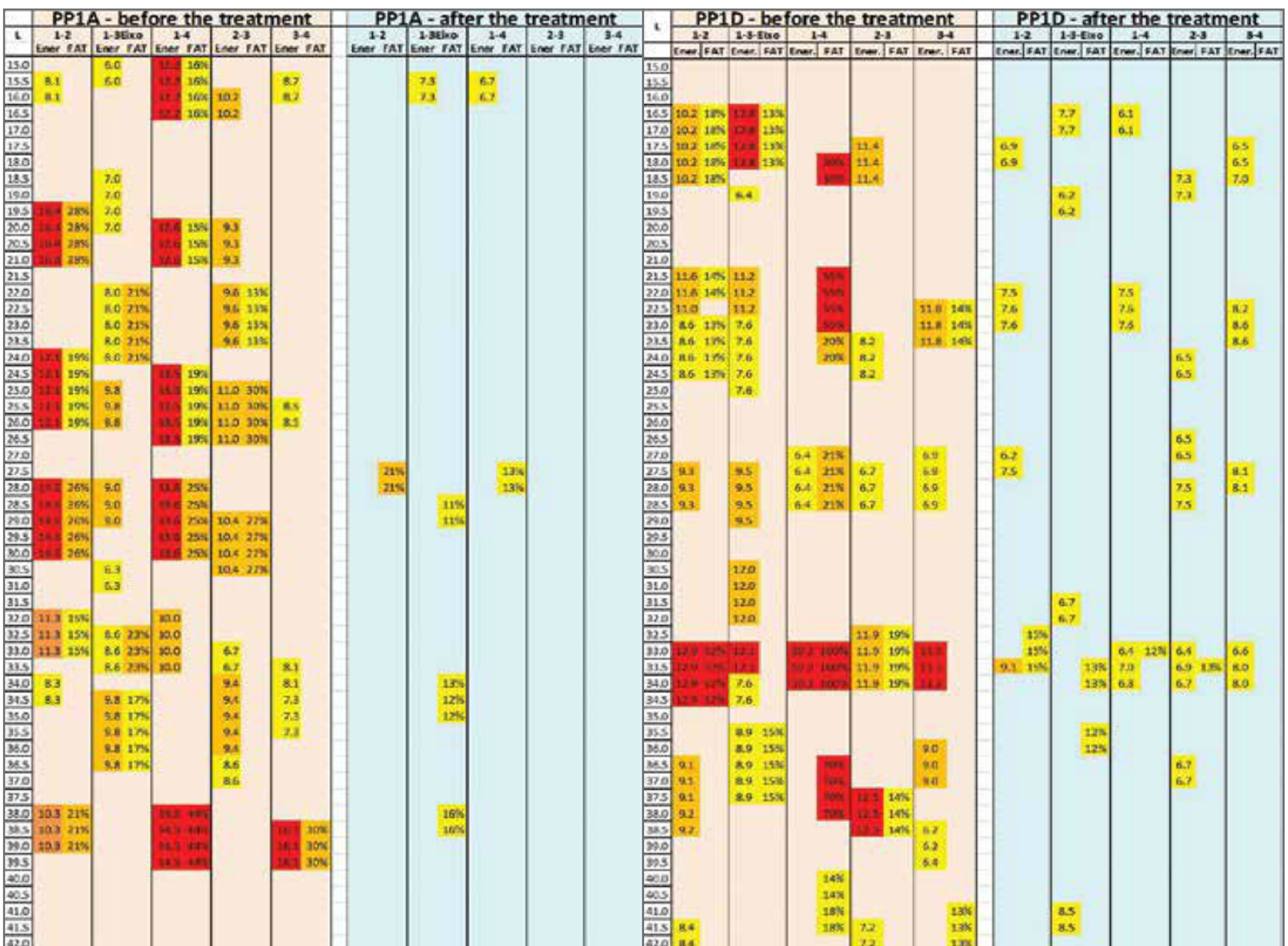

Figure 10: Results of FAT and energy of piles PP1A and PP1D before and after treatment