Before the test they have to be filled with water (to obtain good coupling) and two probes are lowered inside two of the

tubes. One of these probes is an emitter and the other a receiver of ultrasonic pulses. Having been lowered to the bottom, the probes are then pulled simultaneously upwards to produce an ultrasonic logging profile. The transmitter produces a series of acoustic waves in all directions. Some of these waves do eventually reach the receiver.

The testing instrument then plots the travel time between the tubes versus the depth. As long as this time is fairly constant, it shows that there is no change in concrete quality. A sudden increase of the travel time at any depth may indicate a flaw at this depth.

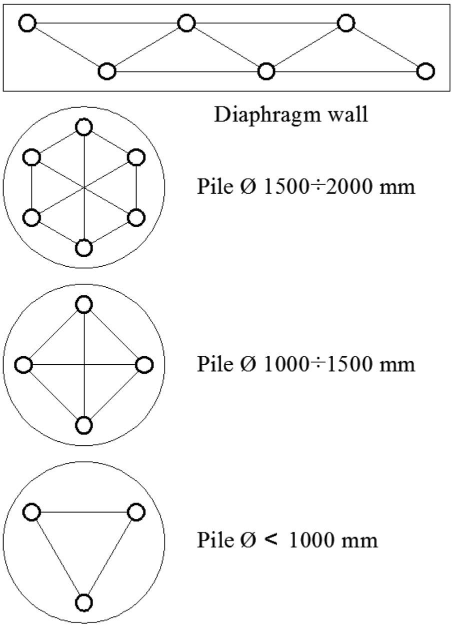

Fig. 8. Typical Access Duct Configurations.

The number of access tubes cast in the pile concrete is a function of the pile diameter, the importance of the pile and, of course, economic consideration. A good rule of thumb is to specify one tube per each 30 cm of pile diameter. Thus for a pile with a diameter of 1.2 m, four tubes will normally do. For best effect, the tubes should be equally spaced inside the spiral reinforcement and rigidly attached to it by wire or spot welding. Where tubes are extended below the reinforcement cage, they have to be stabilized by suitable steel hoops.

2.6 Cross-Hole Sonic Logging Results

Usually the report includes presentation of Cross-Hole Sonic logs for all tested tube pairs including:

- Presentation of the traditional signal peak diagram as a function of time plotted versus depth.
- Computed initial pulse arrival time or pulse wave speed versus depth.
- Computed relative pulse energy or amplitude versus depth.

A Cross-Hole Sonic log will be presented for each tube pair. Defect zones, if any, will be indicated on the logs and their extent and location discussed in the report text. Defect zones are defined by an increase in arrival time of more than 20 percent relative to the arrival time in a nearby zone of good concrete, indicating a slower pulse velocity.

2.7 Tomography by the data of Cross-Hole Sonic Logging

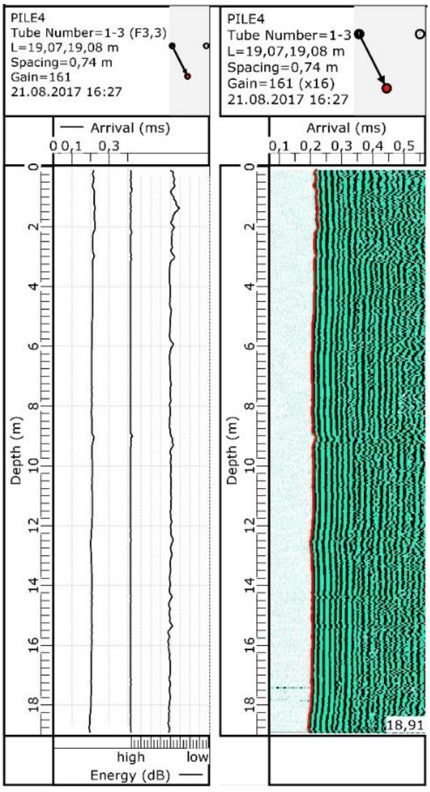

Fig. 9. Typical Ultrasonic Profile.

The same procedure, which is carried out in two dimensions on a single profile, can be used in three dimensions for the whole pile. In this case, the pile is divided into elementary voxels, or volume pixels, this process is usually called a tomography.

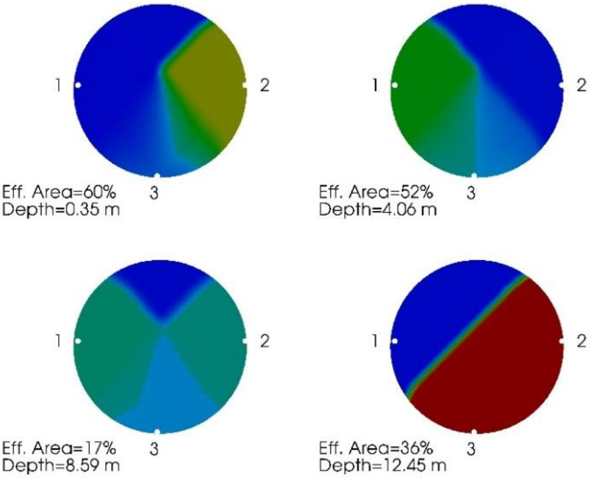

Fig. 10. Horizontal cross-sections of pile in PDI-TOMO software.

Tomography is a mathematical procedure that is applied to Crosshole Sonic Logging (CSL) data, providing the user with a visual image of a shaft's internal defects. The procedure involves solving a system of equations based on First Arrival Times (FAT) in order to calculate wave speeds at various points within the shaft. Tomography wave speeds distributed throughout the shaft are directly proportional to density, indicating concrete quality. PDI-TOMO is an extension of the CHA-W software designed for superior tomographic analysis results from CHAMP data with increased efficiency for the user.

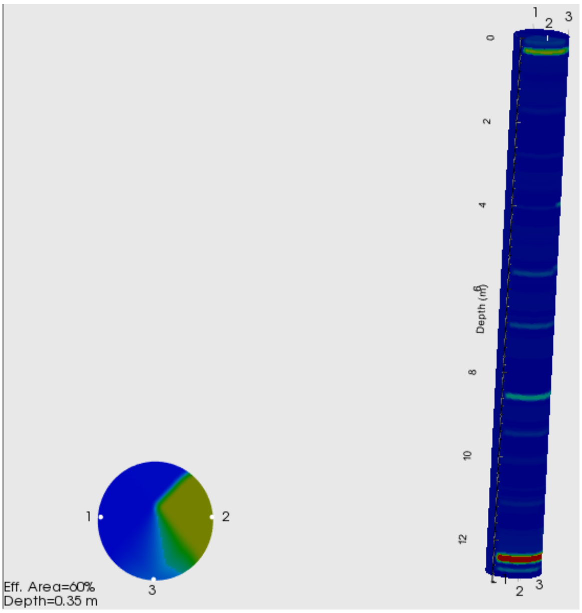

Fig. 11. Three-dimensional visualization in PDI-TOMO software.

PDI-TOMO software features:

- Provides a more precise location, shape and size of defective areas within a shaft.
- Offers an intuitive visual identification of the damaged areas and generates easily comprehensible and professional outputs for the consumer of the CSL reports.
- Provides a valuable add-on service for the testing engineer.

2.8 Cross-Hole Sonic Testing Constraints

The Cross-Hole Sonic Test will normally detect the following items:

- Finds multiple defects, depth and quadrant.
- Finds "soft bottoms" if tubes go to bottom.
- Finds voids better than soil inclusions.
- Finds larger defects easier than small defects.
- Waterfall, FAT (First arrival time), & energy all help find defect.
- Not sensitive to surrounding soils or pile length.

The Cross-Hole Sonic Test will normally not detect the following items:

- Cannot find diameter changes or bulges.
- If too few tubes, can miss a defect.
- Can find defect on direct path.
- Cannot find defect outside cage.
- Major diagonal defects more difficult to find.
- Need more than 4 tubes for 1500 mm pile (recommend 6 tubes for shaft this size).

2.9 Comparison test results obtained by two methods

In 2017 at the construction site of LRT in Astana city, more than 700 bored piles tested for checking the integrity by using two methods: 25 % by Cross-Hole Sonic Logging and other 75 % by Low Strait Test. A technical assignment for integrity testing piles is:

- if one foundation of the bridge consists of four bored piles, then one pile is tested by Cross-Hole Sonic Logging and other three piles tested by Low Strait Test.

- if one foundation of the bridge consists of six bored piles, then two pile is tested by Cross-Hole Sonic Logging and other four piles tested by Low Strait Test.

One of the tested pile PR16-2 contained a serious defect of integrity.

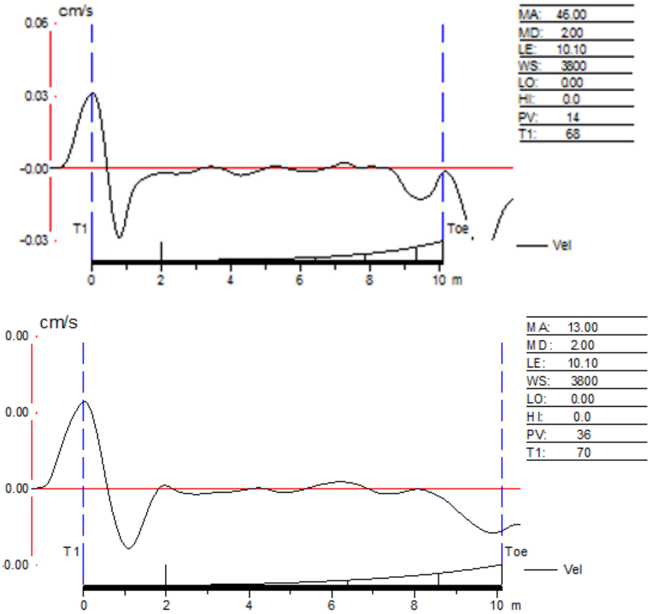

Fig. 12. Two reflectograms of one bored pile PR16-2 obtained by Pile Integrity Tester - PIT-QV.

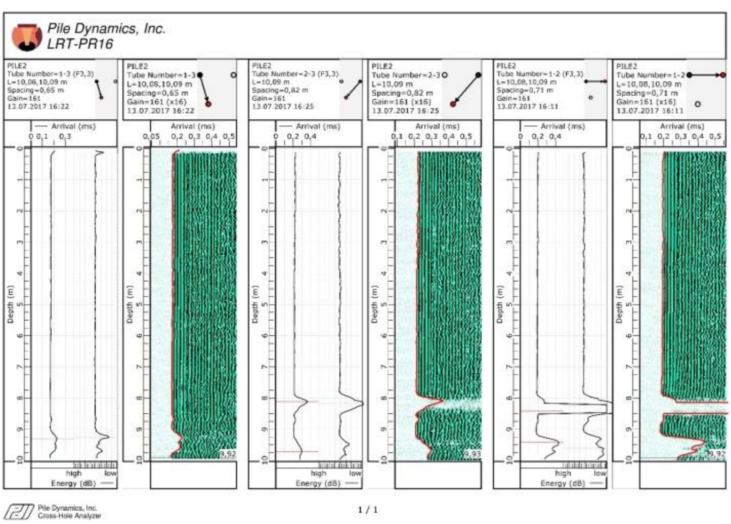

Fig. 13. Three Ultrasonic Profile of one pile PR16-2.

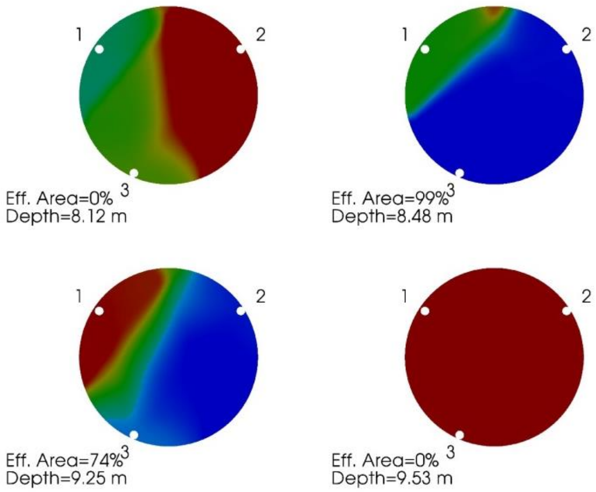

Fig. 14. Horizontal cross-sections of pile PR16-2 in PDI-TOMO software.

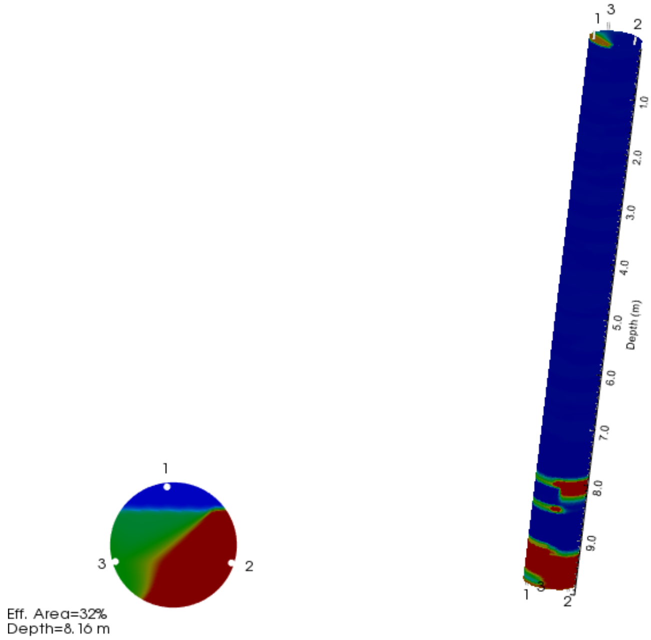

Fig. 15. Three-dimensional visualization in PDI-TOMO software for bored pile PR16-2.

Analyzing the data obtained by Low Strain Test (Fig. 11) we can say only that at the depth 8.5 m this pile has crack and its cross-section is decreasing.

Analyze the data of Cross-Hole Sonic Test can show 3D location of cracks, approximately size of cracks, effective cross-section of pile at any depth. Cross-Hole Sonic Test provide more useful information about integrity and allows the engineer to evaluate the seriousness of the problem and the possibility of using this pile in foundation.

3 Conclusions

The cost of a quality control program for each construction site is very reasonable, and in any case much lower than the potential loss caused by an undetected defect of foundation. The Low Strain test is a powerful quality-control tool, not so expensive and need about one minute for application but we must never forget that it is not omnipotent. Since the sonic method is based on the use of stress-waves, it can identify only those pile attributes that influence wave propagation and have a fairly large size.

The Cross-Hole Sonic Logging method more accurate, allow estimating the size and position of cracks. Although the access tubes introduce an extra expense item, the cross-hole test compensates for this by allowing the testing equipment to approach potential flaws. An additional advantage of this test is the enhanced resolution: while the sonic test uses a wavelength of at least two meters, the cross-hole method utilizes ultrasonic frequencies, with typical wave lengths of 50 to 100 mm. Since resolution is strongly dependent on the wave length, the cross-hole method enables us to detect much smaller flaws with high accuracy.

4 Acknowledgements

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