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Eurasian National University

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**МАЗМҰНЫ/ CONTENTS/ СОДЕРЖАНИЕ**

IRSTI 67.11.29

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# Checking Integrity of Bored Piles Using Two Methods: Low Strain Method and Cross-Hole Sonic Logging - Experience of Application

**Abstract.** *At present, in Astana city is going on works by construction public transport system LRT (Light Railway Transport). LRT is an overhead road with two railway lines. The first stage of construction is including construction of overhead road (bridge) with 22,4 km length and 18 stations. The foundation of bridge is the bored piles with cross-section 1.0÷1.5 m and length 8÷35 m. Design bearing capacity of piles is 4500÷8000 kN. For boring soil using Chinese drilling rigs Zoomlion without casing. To maintain the walls of boreholes in sand and gravel soils using polymer slurry. In these conditions, very important to control integrity of concrete body of each bored piles. For checking integrity applying two methods - Low Strain Method and Cross-Hole Sonic Logging. This paper aims to to discuss the advantages and disadvantages of each method using the examples of a real application.*
**Keywords:** *bored pile, defect, Cross-hole analysis, Pile load test, non-destructive method.*

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**Introduction.** In the spring of 2017, in Astana city was started works by construction public transport system LRT (Light Railway Transport). The cost of the project is about 1.9 billion dollars. Construction work produced by a Chinese state-owned company «China Railway Asia-Europe Construction Investment Co». LRT is an overhead road with two railway lines. The first stage of construction is including construction of overhead road (bridge) with 22,4 km length and 18 stations. Height of the bridge is 7÷14 m above the ground. Overhead road based on columns every 30 meters. The foundation of each column is include 4 or 6 bored piles with cross-section 1.0÷1.5 m and length 8÷35 m. Design bearing capacity of each bored piles is from 4500 to 8000 kN.

To reduce the time for construction and cost of piling works Chinese companies are use Chinese drilling rigs Zoomlion without casing. To maintain the walls of boreholes in sand and gravel soils using polymer slurry. Application of polymer slurry allow reducing time for drilling, allow to use less powerful drilling rigs and equipment, but at the same time increase the risk of collapsing soil during drilling or concreting piles. In these conditions, very important to control integrity of concrete body of each bored piles. For checking integrity of bored piles applying two methods - Low Strain Method and Cross-Hole Sonic Logging.

**Integrity Testing.** All those who have experience in reinforced concrete structures encountered columns, which after dismantling the formwork exposed air voids and honeycomb. Although these columns may have been cast with good-quality concrete, in properly assembled forms and with careful vibration, they still exhibit defects. Cast-in-situ piles are also columns, but instead of forms made of wood or metal we have a hole in the ground. This hole may pass through layers of dumped

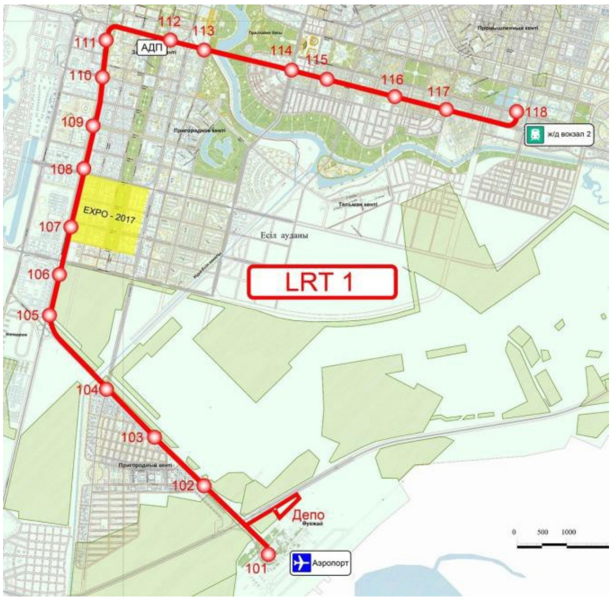


Figure 1. Map of First Line LRT

fill, loose sand, organic matter, and ground water, which may be fast flowing or corrosive. Obviously, such conditions are not conducive to a high-quality end product. The fact that on most sites we still manage to get excellent piles is only a tribute to a dedicated team that makes this feat possible: geotechnical engineer, structural engineer, quantity surveyor, contractor, site supervisor and quality control laboratory. This is obviously a chain, the strength of which is determined by the weakest link. A flaw is any deviation from the planned shape and/or material of the pile. A comprehensive list of events, each of which can lead to the formation a flaw in a pile: use of concrete that is too dry, water penetration into the borehole, collapse in soft strata, falling of boring spoils from the surface, tightly-spaced rebars etc.

Therefore, we have to face the fact that on any given site some piles may exhibit flaws. Of course, not all flaws are detrimental to the performance of the pile. Only a flaw that, because of either size or location, may detract from the pile's load carrying capacity or durability is defined as a defect. The geotechnical engineer and the structural engineer are jointly responsible to decide which flaw comprises a defect.

The two techniques currently dominating pile integrity testing, namely the Low Strain Method and Cross-Hole Sonic Logging, both utilize sound waves (Amir et al 2009).

**Low Strain Method.** The low strain (sonic) method for the integrity testing of piles is aimed at routinely testing complete piling sites. To perform this test, a sensor (usually accelerometer) is pressed against the top of the pile while the pile is hit with a small hand-held hammer. Output from the sensor is analyzed and displayed by a suitable computerized instrument, the results providing meaningful information regarding both length and integrity of the pile.

The surface vibrations are measured through an accelerometer attached to the top of the pile. Although the acceleration curve could be interpreted directly, integration to velocity generally enhances the record by bringing out details otherwise overlooked. The pile top acceleration signal, is therefore digitized and stored in the PIT device memory, and it is numerically integrated to produce a velocity signal. It should be noted that v is a particle velocity, i.e., the actual velocity of movement of the pile top surface.

**Wave Speed in Concrete.** The Impact wave speed in concrete depends on the quality of the concrete and for in-situ casted piles the curing time of the concrete. The wave speed is used to determine the length of the pile based on the return signal. An example of the wave speed in concrete is shown below.

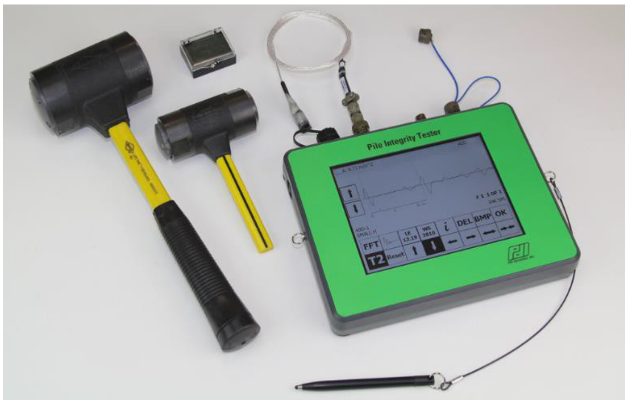

Figure 2. Pile Integrity Tester - PIT-QV

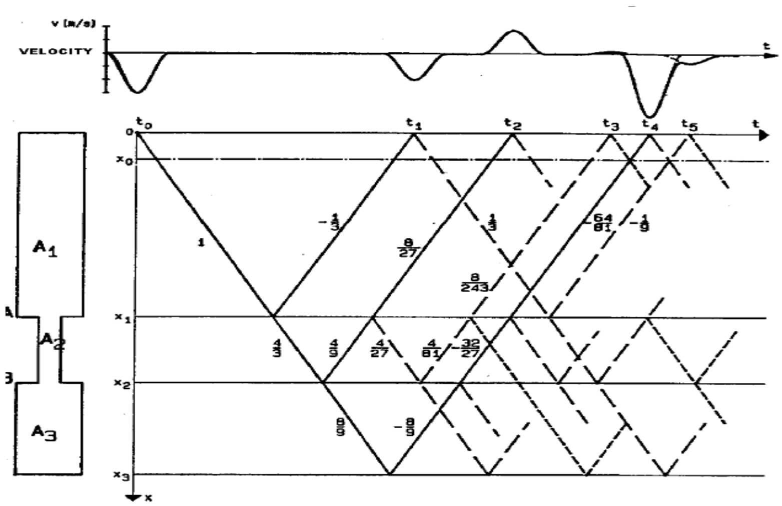


Figure 4. Characteristics for a rod with a reduced cross - section (A2=A1/2, A3=A1)

Table 1. Soil Properties Used in Analysis

| Concrete quality | Impact wave speed (m/s) |
|---|---|
| Bad | <2.700 |
| Acceptable | 2.700-3.300 |
| Good | 3.300-3.800 |
| Very good | 3.800-4.000 |
| Excellent | 4.000-4.500 |
| Unlikely normal conditions | >4.500 |

**Interpretation results obtained by Low Strain Method.** An assessment by this method can give a rapid and accurate appraisal of pile integrity. An integrity test will indicate when a pile should be investigated further but it cannot give information about any load carrying capacity of the pile.

Interpretation of the results obtained must take into account the specific pile circumstances, i.e. construction technique and localized soil conditions. An anomaly does not necessarily indicate a deficiency in the pile, but would certainly merit further investigation to establish the cause of the anomaly. Full interpretation of the signal responses must only be undertaken by fully trained personnel.

For interpretation ten classes are distinguished:

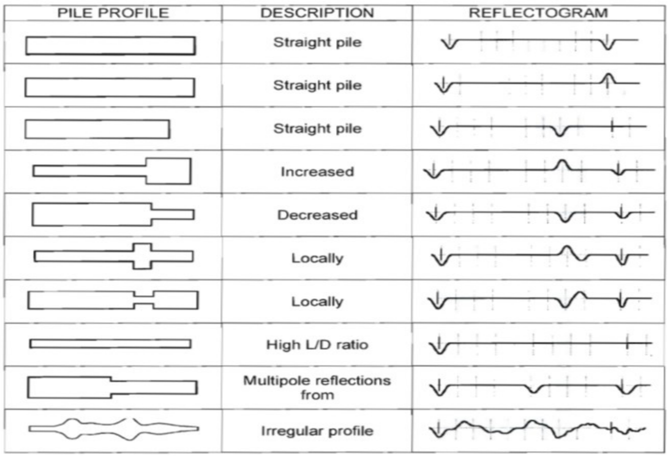


Figure 4. Typical piles with respective reflectograms

**Low Strain Testing Constraints.** The following items may often be detected:
- Pile length.
- Inclusions of foreign material with different acoustic properties.
- Cracking perpendicular to the axis.
- Joints and staged concreting.
- Abrupt changes in cross section.
- Distinct changes in soil layers.

All physical measurements have limitations, and low strain (sonic) test probably has more limitations than any other test. For instance, the sonic test will normally not detect the following items:
- The toe reflection when the L/D ratio roughly exceeds 20 (In hard soils) to 60 (In very soft soils).
- Gradual changes in cross-section.
- Minor inclusions and changes in cross-section.
- Impedance changes of small axial dimension.
- Small variations in length.
- Features located below either a fully-cracked cross section or a major (1:2) change in impedance.
- Debris at the toe.
- Deviations from the straight line and from the vertical.
- Load-carrying capacity.
- The consistency of concrete cover.
- The length of reinforcement.

**Cross-Hole Sonic Logging.** The Low Strain method belongs to the external test- methods, as it accesses only the top of the pile. Ultrasonic logging, on the other hand, is intrusive and necessitates the prior installation of access tubes (usually two or more) in the pile.

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.

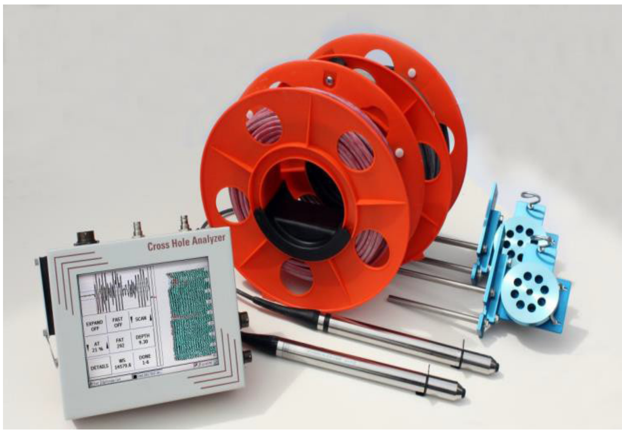


Figure 5. Cross-Hole Sonic measuring device – CHAMP:
computer, cable, depth encoders, test probes

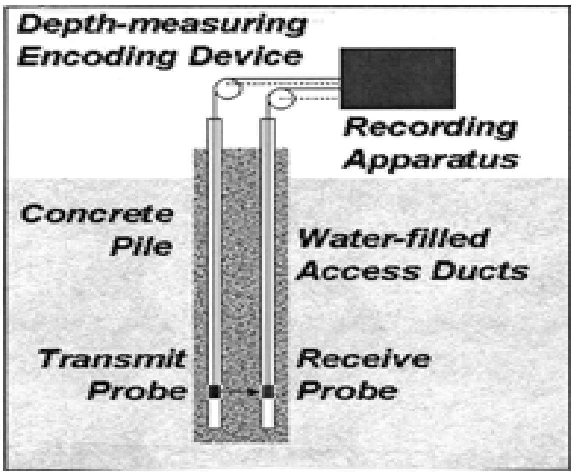


Figure 6. Test Arrangement

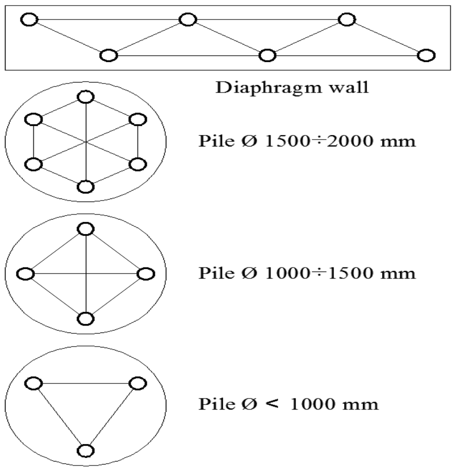


Figure 7. Typical Access Duct Configurations

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.

**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.

**Tomography by the data of Cross-Hole Sonic Logging.** 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.

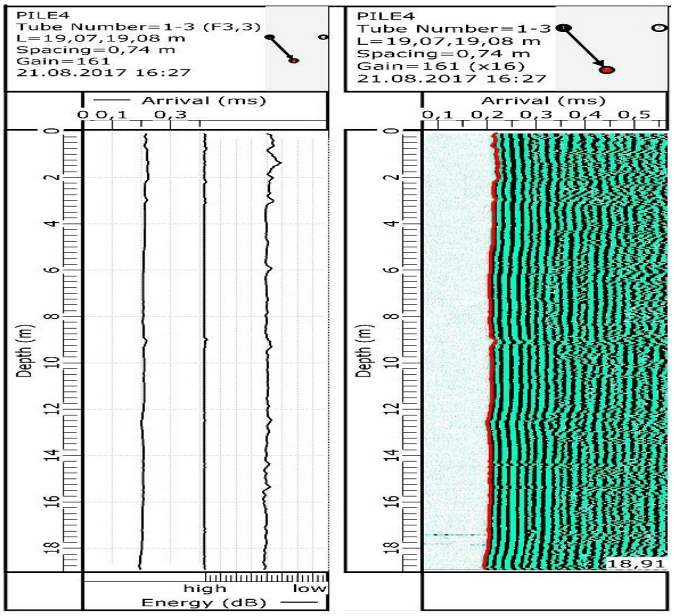


Figure 8. Typical Ultrasonic Profile

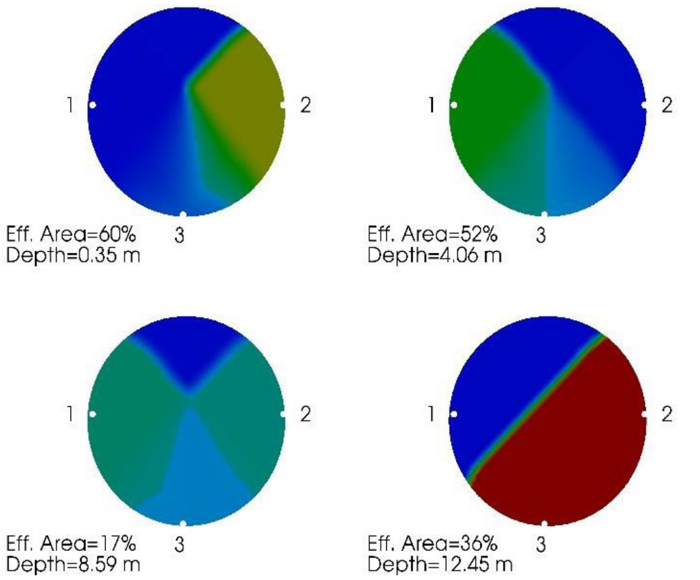


Figure 9. Horizontal cross-sections of pile in PDI-TOMO software

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 the 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.

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.

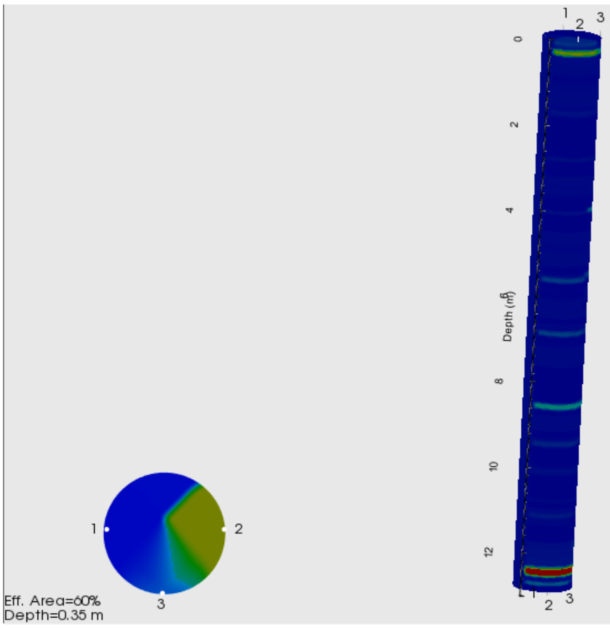


Figure 10. Three-dimensional visualization in PDI-TOMO software

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 the bottom.
- Finds voids better than soil inclusions.
- Finds larger defects easier than small defects.
- Waterfall, FAT (First arrival time), & energy all help find a 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 are more difficult to find.
- Need more than 4 tubes for 1500 mm pile (recommend 6 tubes for shaft this size).

**Comparison test results were obtained by two methods.** In 2017 at the construction site of LRT in Astana city, more than 700 bored piles were integrity tested by using two methods: 25 % by Cross-Hole Sonic Logging and other 75 % by Low Strait Test. Chinese customer gives a technical assignment for integrity testing piles:

- 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.

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 provides 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.

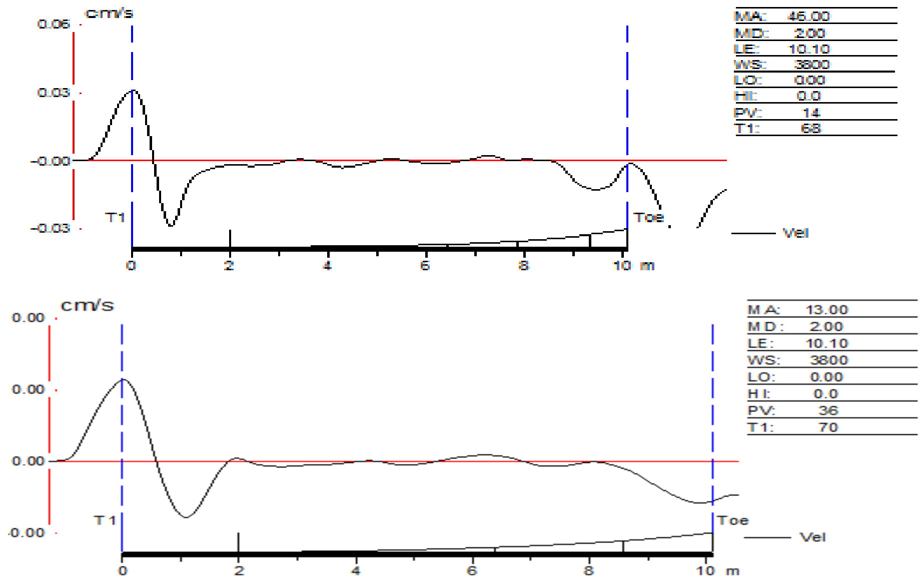


Figure 11. Two reflectograms of one bored pile PR16-2 obtained by Pile Integrity Tester - PIT-QV.

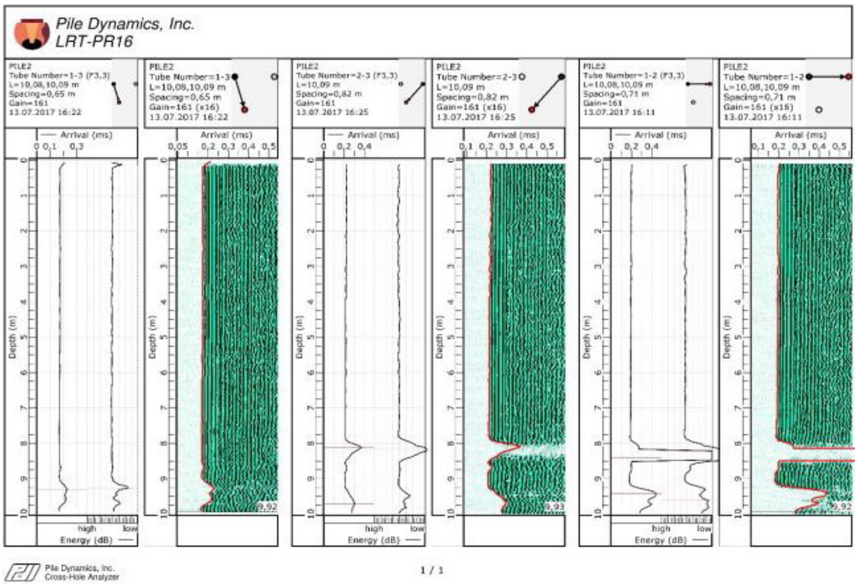


Figure 12. Three Ultrasonic Profile of one pile PR16-2

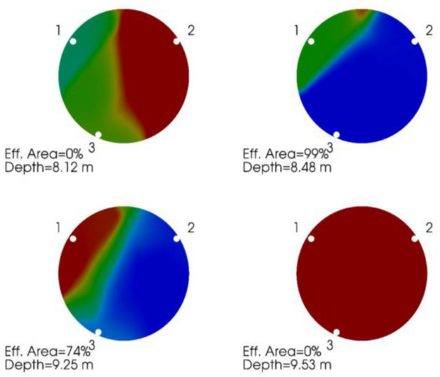


Figure 13. Horizontal cross-sections of pile PR16-2 in PDI-TOMO software

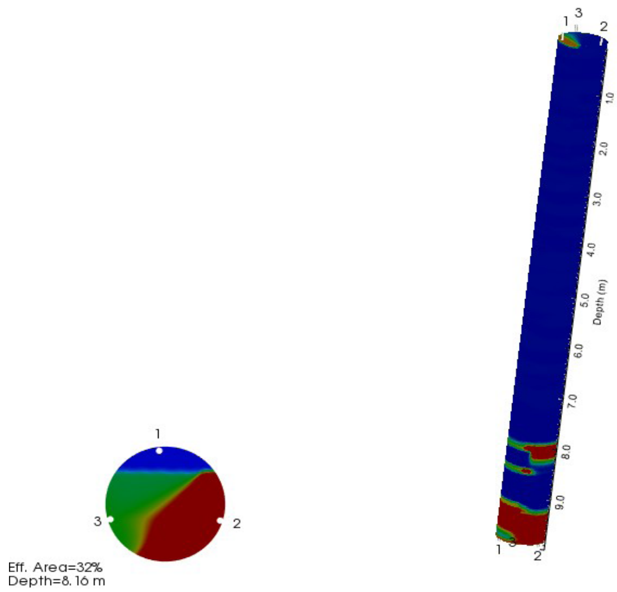


Figure 14. Three-dimensional visualization in PDI-TOMO software for bored pile PR16-2

**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 needs 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.

Cross-Hole Sonic Logging method is more accurate. It allows 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.

**References**

1. Joram M.A. Pile Integrity Testing. –Israel, 2009.

2. ASTM Standard D 5882. Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations. ASTM International. West Conshohocken. PA.-URL: www.astm.org. 2000.

3. ASTM Standard D 6760. Standard Test Method for IntegrityTesting of Concrete Deep Foundations by Ultrasonic Crosshole Testing. ASTM International. West Conshohocken. PA. 2002.  -URL: www.astm.org.

4. White, B., Nagy, M. & Allin, R. Comparing cross- hole sonic logging and low-strain integrity testing results// Proceedings of the 8th Internationl Conference of Application of Stress Wave Theory to Piles. Lisbon. -2008.- P. 471- 476.

5. Bungenstab  F.C, Beim J.W. Continuous Flight Auger (CFA) Piles – A Review of the Execution Process and Integrity Evaluation by Low Strain Test. Buenos Aires. Argentina. -2015. - P. 414-421. IOS Press.

6. Massoudi  N., Teferra W. Non-Destructive Testing of Piles Using the Low Strain Integrity Method// Proceedings of the Fifth International Conference on Case Histories in Geotechnical Engineering. -New York. -2004. - P. 1–6.

**References**

1. Joram M.A. Pile Integrity Testing. (Israel , 2009).

2. ASTM Standard D 5882. Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations. ASTM International. West Conshohocken. PA. Availadle at: www.astm.org. 2000.

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**Бұрғыланған қадалардың тұтастығын екі әдіспен тексеру: төмен деформация әдісі және көлденең ұңғымалық акустикалық каротаж-қолдану тәжірибесі**

**Аңдатпа.** 2017 жылы Нұр-Сұлтанда (Қазақстан) «Болашақ энергиясы» ЭКСПО-2017 халықаралық көрмесі өткізілді. Нұр-Сұлтанда өнер орталығы, энергетикалық залдар және жабық сауда-ойын-сауық павильондары бар тұтас қала пайда болады. Көрме кешені 173,4 гектар аумақты алып жатыр. Жетекші құрылыс компаниялары «Болашақтың қаласын» тұрғызады. Қазіргі уақытта ЭКСПО-2017 жобасының іргетасы Қазақстанның Нұр-Сұлтан қаласында заманауи геотехнологиялардың көмегімен салынған. О-тәрізді ұяшықтарға жүктеме сынақтары және әдеттегі статикалық сынақтар жүргізіліп, олардың нәтижелері салыстырылды. О-ұяшықтарды сынау әдісі зерттелді және оны үлкен диаметрлі қадалар үшін қолданудың артықшылықтары сипатталған. O-cell сынақ әдісі қарапайым бұрғыланған қадаларды сынауға қарағанда бірқатар ықтимал артықшылықтарды ұсынады, мысалы, үнемділік, жоғары жүктеме сыйымдылығы, ығысу/жүк көтергіш компоненттер, қауіпсіздікті арттыру, рок ұялары және жұмыс аймағын азайту.

**Түйін сөздер:** буронабивная қада, ақау, көлденең ұңғыманы талдау, қаданы жүктемелік сынау, бұзбайтын әдіс.

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*[2]Инженер тест, ТОО «KGS»,Нур-Султан, Казахстан*

**Проверка целостности буронабивных свай двумя методами: методом низких деформаций и поперечным скважинным акустическим каротажем - опыт применения**

**Аннотация.** В настоящее время в г. Нур-Султане продолжаются работы по строительству системы общественного транспорта LRT (Light Railway Transport). LRT - это подвесная дорога с двумя железнодорожными линиями. Первый этап строительства включает в себя строительство воздушной дороги (моста) протяженностью 22,4 км и 18 станций. Фундаментом моста служат буронабивные сваи сечением 1,0÷1,5 м и длиной 8÷35 м. Расчетная несущая способность свай составляет 4500÷8000 кн. Для бурения

грунта используют китайские буровые установки Zoomlion без обсадной колонны. Для поддержания стенок скважин в песчано- гравийных грунтах используют полимерную суспензию. В этих условиях очень важно контролировать целостность бетонного тела каждой буронабивной сваи. Для проверки целостности применяют два метода - метод низких деформаций и метод поперечного скважинного звукового каротажа. Целью данной работы является обсуждение преимуществ и недостатков каждого метода на примерах реального применения.

**Ключевые слова:** буронабивная свая, дефект, поперечный анализ скважины, нагрузочные испытания сваи, неразрушающий метод.

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