Checking the integrity of piles by seismoa cousticdefectos copy

Evgeniy Degaev¹ and Vladimir I Rimshin¹

¹ Moscow State University of Civil Engineering, Yaroslavskoes shosse 26, Moscow, 129337, Russia
E-mail: degaev@inbox.ru, v.rimshin@niisf.ru

Abstract. The article presents the results of studies of pile continuity by seismic acoustic flaw detection. The test results revealed the dependence of soil homogeneity on the signal frequency. At the interface of two different density soils, the sound wave is reflected and partially passes on, creating characteristic peaks of false defects. In order to eliminate false defects, geological studies of soils with layer-by-layer occurrence are necessary.

1. Introduction
Pile foundations are one of the main and important types of work in construction [1-3], the quality of which dictates on the future condition of the building or structure under construction.

In cases of driven piles, poor quality might result from violation of safety during transportation [5-8], warehousing and installation on the boom of pile-breaking units, poor execution of the joints of composite piles, as well as hidden defects in the manufacture of the pile trunk (factory marriage), which cannot be determined visually (due to microcracks in the pile trunk, heterogeneity of the material, mismatch with the design class, brand of concrete, etc.). As a result, dynamic impact piles with such factory defects become unusable, and the continuity of the pile is broken. The development of cracks can result from human factors such when the operator corrects the verticality of the pile in the process of hammering, a problem often observed in construction practice [4-6].

Violation of the continuity of the pile trunk can lead to a significant decrease in the bearing capacity of piles, both on the ground and on the material. This applies equally to the device of piles by any known technology-to bored, bored, driven or depressed piles.

In accordance with SP 45.13.330.2012 "Earthworks, foundations and foundations," at the device of drilling and bored piles quality control of the made piles shall be carried out. Checking the continuity of bored piles in the conditions of the construction site can be complete or selective depending on the tasks.

Traditional pile tests with static and dynamic loads, being the most indicative tests, can only determine the bearing capacity of the piles, but in no way can guarantee the quality of the pile as a reinforced concrete structure.

It is virtually impossible to identify defects that violate the continuity of the pile trunk under the traditional control system. Quality control [10-12] during drilling and concreting the pile shaft is carried out directly, but in many cases insufficiently, on the construction site. Currently, proper postoperative monitoring of compliance with all parameters of the technology is, as a rule, not conducted.

In some cases, the quality control of pile foundations are limited to keeping logs and acts of hidden works, as well as in the selection of samples of concrete when filing. Sampling of concrete when it is fed into the well can serve only for indirect assessment because the strength of concrete in cubes and concrete in the well are different. In this case, this control refers to determining the quality of compliance of piles with project documents [9-10], but not to the quality of its manufacture or the detection of violations of the continuity of the trunk. Because of these problems, pile construction requires a different quality control system.

Currently, there are at least four methods for determining the continuity of piles:
• the selection of core;
• ultrasonic testing;
• thermometric method;
• acoustic testing.

A direct method of determining the continuity of piles is the selection of concrete cores from the pile body by drilling the barrel of its core method and then testing the cores for strength. This method has significant disadvantages: high cost, low speed of concrete drilling.

Ultrasonic testing is used to control the uniformity of concrete in piles, bridge abutments, and other structures. This method of checking continuity is considered the most accurate of indirect methods, but has sufficient disadvantages to use it only in rare cases. For implementation of such method of control in the chamber installed on all its length are metal or plastic tubes of a certain diameter for placement of the ultrasonic transducer. In the manufacture of piles, these tubes often are damaged and the quality of the pile is not possible to assess.

The thermometric method is a new direction of nondestructive control of pile foundations continuity. The method is based on measuring the temperature of concrete in the pile during concrete hardening using a thermometric probe. In the process of making the pile, damage to the probe is also possible. Also, this method is only applicable in the concrete hardening process when heat is release during a exothermic hydration reaction.

Seismoacoustic flaw detection is one of the most modern methods of pile testing in world practice in recent years. This detection method is based on the theory of propagation of sound (high and low frequency) in a solid. The test allows performance of a continuity analysis of all types of piles and can identify defects in the pile body. None of the shortcomings of previously described methods shortcomings of the previous methods are evident in this method of control of the continuity of piles. However, in Russia, seismoacoustic flaw detection is used rarely because there are no regulatory and research bases for applying tests and provide test results to construction control services [5-10]. As a rule, seismoacoustic flaw detection is used in conjunction with other methods.

The purpose of this work is to present the results of pile tests in different soils by seismic-acoustic method with decoding of reflectograms.

2. Materials and Methods
Non-destructive testing of pile continuity by seismic acoustic flaw detection is intended for use in field testing of piles of all types, regardless of the method of their immersion or device in the foundation. The method is based on the hardware recording of the response of the studied pile to the external impact with the specified pulse parameters (see figure 1).

The recorded and accumulated signals, after appropriate analysis, allow the location of defects and damages to be recognized. As a result, the continuity of the material, the length of the element, the location of violations of the continuity of the pile in the form of cracks, voids, and foreign inclusions is controlled. Registration of signals is carried out by means of the sensor-accelerometer installed on the head of the pile, connected to a special computer equipped with software for digitization and interpretation of the obtained data. The results of data processing are presented in the form of a computer graphic image (reflectogram) indicating the length of the element, continuity, and the presence and location of damage.
After hitting the end of the pile with a hammer, the longitudinal wave of tension-compression propagates along the pile trunk with some speed $c$. Because the acoustic properties of concrete are different from the acoustic properties of dispersed soils, the pile is a waveguide with relatively small energy losses for attenuation and re-emission into the geomassive. The sound wave is reflected at the interface of media (concrete-foreign inclusion, concrete-soil, etc.). The time interval between the initial hammer impact and reflect from the boundary of the medium is measured by the instrument and equals the time $t$ required for the wave propagation in the pile shaft of length $l$ twice (down and up):

$$ t = \frac{2l}{c} \tag{1} $$

The length of the pile $l$, is determined by an indirect method based on the time interval $t$ measured by the device, while the velocity of the longitudinal wave $c$ in the pile is considered known:

$$ l = \frac{ct}{2} \tag{2} $$

Using Newton's second law, the displacement of an elastic wave is characterized by the speed of sound, which depends on the properties of the medium and is determined by the formula:

$$ c = \frac{E_d}{\rho} \tag{3} $$
For building materials, in particular for concrete, in the absence of a direct functional relationship, there is a fairly stable and close correlation (i.e., a statistical relationship) between the speed of sound and the strength of the material – in a stronger material, the speed of sound is higher. Pile defects can be characterized by changes in cross-sectional area or material properties $E$ and $p$. When a wave encounters inhomogeneity, it is partially reflected back, partially passes forward (figure 2).

![Figure 2. Scheme of sound wave propagation in a pile with a defect.](image)

3. Results and Discussion
The obtained reflectograms on real objects differ significantly from idealized graphs, which are indicated in various scientific and regulatory sources [1-9]. One of the causes of signal distortion is heterogeneous ground. In some cases, a distorted signal from rocky ground (or inclusions in it) can be mistaken for numerous defects in the pile shaft.

The method, with the simplicity of conducting tests in the field, requires enough time and knowledge for subsequent data processing [12-15] to exclude erroneous conclusions. To eliminate the distortion received from different layers of soil, it is necessary to study the design and working documentation and when processing signals to focus on geological studies [16-22]. Shown in figures 3-5 are the results of signal processing in different soils.
Figure 3. Pile reflectogram in low-strength Sandstone, RQD-40%.

Figure 4. Pile reflectogram in soil with different layers: 1-light solid loam, eC; 2-low strength mudstone dense, RQD-20%; 3-low strength Sandstone, RQD-40%.
Figure 5. Reflectogram of the pile in the soil with different layers: 1a-loam heavy dusty solid, dQIII; 2-clay light dusty solid, dQIII; 2a-loam heavy dusty refractory, dQIII; 4-loam heavy solid, eC; 5-low strength mudstone dense, RQD-20%; 6 - Sandstone maloprochny, RQD-40%.
The obtained results confirm the influence of soil homogeneity on signal purity. The more the soil is heterogeneous in structure, the more false characteristic peaks are obtained on the reflectogram. To eliminate false peaks, software complexes for processing the results can filter out the high-frequency signals to facilitate data processing.

4. Conclusions
Advantages of seismoacoustic flaw detection:
- detection of defects in piles at an early stage of work;
- ability to process any available pile by one operator;
- ability to determine the length of the pile;
- speed and cost-effectiveness of the method.

The main difficulty in conducting seismoacoustic flaw detection of piles is that this method is indirect and has a measurement error of 5-10%. This method is used as a preliminary before testing piles with static or dynamic load. Without a geological section it is quite difficult to predict the continuity of the structure because the heterogeneity of the soil can give false peaks on reflectograms [23-31].

References
[1] ASTM D5882-16. Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundation.
[2] NTTPRC 07-02. 2-2011. Development of pile continuity testing.
[3] Procedure for conducting tests by acoustic flaw detection (Integrity testing of piles). Profound BV. CB Waddinxveen. 2006.
[4] Pile Echo Tester. PET (PilETest) User Manual.
[5] Methods for diagnostics of piles by means of acoustic testing. Scientific and production enterprise "Interpribor".
[6] Recommendations for use of the device PDS-MG4. "SKB Stroypribor».
[7] ISC.468119.003 RE-LU. Method of measuring the length of piles using the device IDS-1.
[8] Technological regulations on the use of nondestructive Express control of pile continuity by "Sonic" method. JSC TSNIIS. 2002.
[9] STO EGEOS 1-1. 2-001-2017. Application of non-destructive testing of pile continuity by seismic-acoustic method.
[10] Borkovskaya V G and Passmore D L 2019 Behavioral engineering model to identify risks of losses in the construction industry. Smart Innovation, Systems and Technologies, 243-250. doi:10.1007/978-3-030-15577-3_24.
[11] Borkovskaya V G 2013 The concept of innovation for sustainable development in the construction business and education. App. Mech. Mater. 475-476, 1703-1706. doi:10.4028/www.scientific.net/AMM.475-476.1703
[12] Borkovskaya V G 2014 Complex models of active control systems at the modern developing enterprises. Adv. Mat. Res. 945-9493012-3015. doi:10.4028/www.scientific.net/AMR.945-949.3012.
[13] Hola J and Schabowicz K. 2010. State-of-the-art non-destructive methods for diagnostic testing of building structures - anticipated development trends. Archives of Civil and Mechanical Engineering, 10 (3), 5-18.
[14] Amir J. M. 1988. Wave velocity in young concrete. Proc 3rd Intl Conf on Application of Stress-wave Theory to Piles, Ottawa, 911-12.
[15] Finno R. J. and Gassman S. L. 1998. Impulse response evaluation of drilled shafts. Journal of Geotechnical and Geoenvironmental Engineering, 124 (10), 965-75.
[16] Thasnanipan N, Maung A W, Navaneethan T and Aye Z. Z. 2000. Non-destructive integrity testing on piles founded in Bangkok subsoil. Proceedings of 6th Conference on the application of stress wave theory to Piles, Sao Paulo, Brazil, Balkema, Rotterdam, 171-7.
[17] Niederleithinger E and Taffe A. 2006. Early stage elastic wave velocity of concrete piles. Cement
& Concrete Composites, 28, 317–20.

[18] Restrepo C. 2000. Stress wave propagation velocity at early ages. Proceedings of 6th Conference on the application of stress wave theory to Piles, Sao Paulo, Brazil, Balkema, Rotterdam.

[19] Yoo J. K. and Ryu D W 2008 A study of the evaluation of strength development property of concrete at early ages. 3rd ACF International conference - ACF/VCA.

[20] Amir E. I. and Amir J. M. 2008 Statistical analysis of a large number of PEM tests on piles. Proc. of 6th Conf. on the application of stress wave theory to Piles, Lisbon, Portugal, IOS Press, 671-5.

[21] Rybak J and Schabowicz K. 2010. Acoustic wave velocity tests in newly constructed concrete piles, NDE for Safety: 40th international conference and NDT exhibition: proceedings, November 10-12, 2010, Pilsen, Czech Republic, 247-54.

[22] Rybak J. 2014. Stress wave velocity tests in early-stage of concrete piles. Concrete solutions: proceedings of Concrete Solutions, 5th International Conference on Concrete Repair, Belfast, Northern Ireland, 1-3 September 2014, 571-76.

[23] Krishan, A. L.; Narkevich, M. Yu; Sagadatov, A., I, Experimental investigation of selection of warm mode for high-performance self-stressing self-compacting concrete. 7th International Symposium on Actual Problems of Computational Simulation in Civil Engineering (APCSCE). Novosibirsk, Russia, Jul 01-08, 2018.

[24] Varlamov, A. A.; Rimshin, V., I; Tverskoi, S. Y. Security and destruction of technical systems. 18th International-Federation-of-Automatic-Control (IFAC) Conference on Technology, Culture and International Stability (TECIS), Baku, Azerbaijan, Sep 13-15, 2018.

[25] Varlamov, A. A.; Rimshin, V. I.; Tverskoi, S. Y. Planning and management of urban environment using the models of degradation theory. 3rd International Conference on Sustainable (ICSC), Moscow, Russia, May 18, 2018.

[26] Kuzina, Ekaterina; Cherkas, Alina; Rimshin, Vladimir. Technical aspects of using composite materials for strengthening constructions. XXI International scientific conference on advanced in civil engineering construction - the formation of living environment (form 2018), IOP Conference Series-Materials Science and Engineering. T. 365, No. UNSP 032053, 2018.

[27] Kuzina, Ekaterina; Rimshin, Vladimir. Deformation Monitoring of Road Transport Structures and Facilities Using Engineering and Geodetic Techniques. International scientific conference energy management of municipal transportation facilities and transport, emmft 2017, Advances in Intelligent Systems and Computing. T. 692, pp. 410-416, 2018.

[28] Cherkas, Alina; Rimshin, Vladimir. Application of composite reinforcement for modernization of buildings and structures. RSP 2017 - XXVI R-S-P SEMINAR 2017 Theoretical foundation of civil engineering. MATEC Web of Conferences, T. 117, No. UNSP 00027, 2017.

[29] Erofeev, Vladimir Trofimovich; Zavalishin, Evgeny Vasilevich; Rimshin, Vladimir Ivanovich. Frame Composites Based On Soluble Glass. Research journal of pharmaceutical biological and chemical sciences. T. 7, V.3, pp. 2506-2517, May-Jun 2016.

[30] Krishan, Anatoli; Leonidovich; Troshkina, Evgenia Anatolievna; Rimshin, Vladimir Ivanovich. Load-Bearing Capacity of Short Concrete-Filled Steel Tube Columns of Circular Cross Section. Research journal of pharmaceutical biological and chemical sciences. T. 7, V.3, pp. 2518-2529, May-Jun 2016.

[31] Krishan, Anatoly; Rimshin, Vladimir; Erofeev, Vladimir. The Energy Integrity Resistance to the Destruction of the Long-Term Strength Concrete. International Scientific Conference Urban Civil Engineering and Municipal Facilities (SPbUCEMF). Saint-Petersburg, Russia, Mar 18-20, 2015.