HBE 2009
Actual trends

INTERSECTII
INTERSECTIONS
www.intersections.ro

The use of non-destructive methods for testing indirect foundations of bridges on A3 motorway

Cristina Romanescu[1], Constantin Ionescu[2]
[1] Bucharest-Comarnic Motorway Direction, RNCMNR, Bucharest, 010873, Romania
[2]Civil Engineering Faculty, Gheorghe Asachi Technical University, Iassy, 700050, Romania

Abstract

For each company in the field of road building and not only the construction quality is of great importance. Therefore the organization of well-documented and standardized tests to accurately identify potential defects is crucial to assess whether the constructed items are of sufficient quality. Some methods are recognized for efficiency and precision, such as sonic echo method and impulse response method. These are used for non-destructive quality assessment and identification of internal defects of concrete pilots. Investigations have shown that these methods provides, in a direct and fast manner the length of pilots, the vertical cross sections irregularities of pilots, and the gaps within. Pilots bored in situ have a high risk of deteriorating and it is therefore important to test them. For this purpose are performed the tests for the integrity of individual vertical or inclined pilots by measuring and analyzing the speed and force as response of the pilot with an impact applied, for all bridges located on the Bucharest-Ploiesti motorway.

Keywords: nondestructive methods, bored pilots, sonic echo technique, the impulse response technique

1. INTRODUCTION

In terms of administrative, A3 Bucharest-Ploiesti motorway starts in 2nd sector of Bucharest (Petricani Street) and continues within Ilfov County (Voluntari, Tunari, Stefanestii de Jos, Moara Vlasiei, Snagov, Gruiu) and Prahova (Balta Doamnei, Gherghita, Draganesti, Rafov, Dumbrava, Berceni, Barcanesti and Ploiesti).

The total length of the Bucharest-Ploiesti motorway section will be 61.8 kilometers, plus about 0.5 kilometers the connection road to DN1.

On the motorway there are designed 17 bridges, 22 passages, 5 road junctions and 64 culverts.

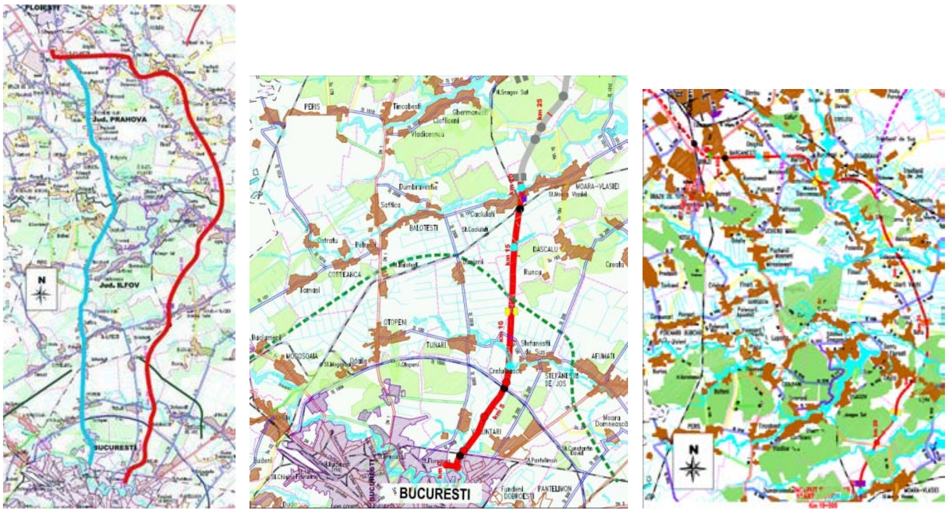

Figure 1. The A3 Bucharest-Ploiesti motorway. Details of the two sections, km 0,000 – 19,500 and km 19,500 – 62,000

Motorway route starts on Petricani Street in Bucharest, with about 1200 meters before the intersection with the Bucharest-Constanta railway, continuing with the Petricani passage over the Bucharest-Constanta double railway, industrial railway of Baneasa to Pantelimon and a road adjacent to the railways.

The general orientation of the alignment will be the north (within the village Voluntari) east of Pipera highway, then passes over a bridge Pipera Lake.

The motorway will overpass the bypass road and the existing rail of Bucharest at km 6+550.

Following the same alignment to the north, the motorway will cross the Pasarea Valley, will pass through the territories of Tunari and Stefanestii de Jos and then will intersect the future Nord motorway belt of Bucharest. The alignment continues across Mostistea Valley, will pass near the western end of Tiganca forest then will overpass the railway Bucharest-Urziceni, then will pass near the Caciulati city. Further, the alignment goes parallel to the railway Caciulati-Snagov Village, on a length of 705 meters on the right, wtihin the railway protection zone and will overpass the communal road DJ101A Caciulati-Moara Vlasiei) and Cociovalistea Valley.

Then the motorway alignment will pass through Vlasia and Surlari forests for 600 meters, and it goes parallel to the eastern limit of the Vlasiei forest for approximately 1500 m.

To allow access to the motorway to and from areas of Moara Vlasiei and Snagov, the Snagov road junction will connect the motorway to the communal road DC 184.

At about four kilometers away from the edge of the forest Vlasiei the motorway crosses over the Teiului Valley, then crosses the county road DJ-101B Gruiu-Lipia, crossing the Gruiu creek and Ialomita river. Ialomita River delimits the administrative territory of Ilfov and Prahova counties.

The motorway continues north-west, crossing a number of communal roads and county road DJ 100 B Lacul Turcului-Gherghita, then Prahova River.It will then pass through Calugareasca forest for a distance of approximately 400 m until its km 45, where the motorway alignment is separated from the one to Albita. Starting this point, the motorway has a general orientation to the west until km 51 and crosses the northern edge of Dumbrava forest and river Teleajen through the southern of Zanoaga town.

From km 51, the general orientation of alignment is to the northwest and the motorway route continues over the brook Ghighiu then Buchilasi southern town and by the northeast of village Rafov and Rafoveanca forest.

After about 700 meters, the motorway overpasses the creek Ghighiu, then the communal road DJ 101D (DN1A - Moara Domneasca), about 300 m from the stream. The motorway follows a westerly direction crossing a series of rural roads (farm); Barcanesti brook is crossed at km 58.

An overpass will be built to cross the National Road 1. After passing DN 1, the motorway will be a general trend to the northwest. Starting here, it will be connected through a road link with 4 lanes with DN 1, meeting with it near the access road at Tatarani.

2. PRESENTATION OF TEST METHODS

The primary requirements for pilot testing are provided in SR EN 1997-1:2004 Eurocode 7: Geotechnical design. Part 1: General rules.

Pilot tests may be performed for research or investigation to investigate the characteristics of resistance and /or deformability in specified actions domain and the integrity and proper execution of the pilot. Pilot tests may be:

- static pilot testing with loading steps;
- pilot testing by the constant loading speed;
- dynamic pilot testing to determine the bearing capacity, and
- integrity tests to measure noise and vibration properties of the pilot to determine the presence of possible anomalies in the body of the pilot.

INTERSECTIONS
INTERSECTII
www.intersections.ro

Romanescu Cristina, Ionescu Constantin

Integrity test methods are the ones applying only for verifying the structural integrity.

Integrity test must be conducted with equipment designed and approved for this purpose and should be done by competent persons in this field also having knowledge of pilots execution techniques and experience in specific field conditions. The equipment must be used in accordance to the instructions from the manufacturer and the pilot must be prepared for this purpose in an appropriate manner.

Records of any integrity tests should specify:
- scope (purpose) of the test;
- test method and procedure;
- test results;
- conclusions on the integrity of the pilot.

According to "SR EN 1536:2004 Execution of special geotechnical works. Drilled pilots" the execution of pilot techniques may be:
- cased / noncased excavation;
- excavation under the protection of stabilizer fluid;
- pilots drilled with conveyer worm.

Depending to the used techniques different information are required to be given about actual work situation, which may influence test results, for example: time of the excavation, disruption in the excavation work, temporarily or permanently tubing, the boring casing depth, depth of the pilot, stratigraphic sheet, groundwater level, supporting mode of the reinforcement, the injection process, deviations from the execution, tilting of the pilot, etc.

Integrity test methods are nondestructive methods of sonic echo and impulse response, whose principles are described below, according to SR ASTM D 5882:2005 - Standardized method for determining the integrity of pilot by tests with small deformation.

This test method covers the procedure for determining the integrity of individual vertical or inclined pilots by measuring and analyzing of speed (obligatory) and force (optional), as the response of the tested pilot with an impact device.

The testing method using low intensity efforts done from the surface is the sonic echo method. (SE). By slight hammering of the concrete element with a hammer a plane pressure wave is induced across its entire length. The induced wave in the upper face of the element goes through it, reaches the lower face, is reflected and returns integrally or partially to the upper face.

If the cross section of the element is not the same throughout its length, if any heterogeneous properties of the tested material, or if discontinuities are present within, then variations of impedance occur pilot and, as a consequence, some or even all the wave is reflected by the impedance changes and returns to the top before the wave reflected from the bottom.

Wave velocity-time variation is recorded. Reflected signal is usually influenced by lateral friction are dependent on the stratification of soil surrounding the pilot.

The formula currently used in the analysis of integrity is:

$$L = c \cdot T/2 \qquad (1)$$

Where L is the depth of foundation (long pilot), c is the speed of pressure wave and T is the time to scroll the waveform from the top to bottom and back. Impedance of pilot z (pilot resistance to changes in pressure wave speed) is given by:

$$z = E \cdot A/c \qquad (2)$$

where A is the cross-sectional area of the pilot and E is Young's module of pilot's material:

$$E = \rho \cdot c^2 \qquad (3)$$

From equations (2) and (3) follows:

$$z = \rho \cdot c \cdot A \qquad (4)$$

Pilot length is determined using the scroll time for the wave reflected from the bottom and wave speed in concrete. Wave speed can be estimated if concrete strength is known or using a pilot having a known length.

Impedance is a function that depends on the cross section area, modulus of elasticity, wave speed within the pilot material and soil depreciation. The position of discontinuities and irregularities in the pilot can be determined in the same way. Equation (4) shows that the impedance change can be caused by changes in pilot cross-sectional area of the pilot or the quality of concrete.

Sonic echo method can be applied to monolith concrete casted pilots and precast pilots made of concrete, steel or wood. By making this test defects such as cracks, holes, earth inclusions, element variations in diameter (i.e. "bottlenecks"), depth of foundation and non-homogenous material of construction may be detected. The method does not provide information on load-bearing capacity of the item.

Returned waves are detected by an accelerometer placed on top of the tested item. Induced pressure wave reflections occur not only in its foot but also along the axis in positions where its impedance is changed. Reflections caused by the wave are located in the measured signal and allows determining the depth of foundation and thus implicitly the length of the pilot, but also determining the positions of defects based on the impedance changes positions.

Test equipment consists of a impulse hammer and one or more accelerometers or geophones placed on the pilot. The hammer pulse can be attached to a force transducer that can measure the impact force and duration. The test involves striking the upper face with a hammer, to generate a wave of energy that goes to the bottom. The wave is then reflected on the bottom of the structure and claims to the top. The accelerometer measures the vibration response to each impact. Signal analyzer or computer processes and displays signals from the transducers.

Analysis can be made in the frequency response using the impulse response method where the depth of reflection is given by

$$L = c(2 \times f) \qquad (5)$$

where f is frequency interval between consecutive peaks of transfer function.

Depth of foundation is assessed by identifying and analyzing time of arrival, the direction and amplitude of reflections measured by transducers over time. The accelerometer increases the signal exponentially over time to show weak reflections.

Method impulse response (IR) uses the same test equipment as the SE method. Testing procedures are similar but different data processing. IR method involves processing the data in the frequency domain, for example, processing the vibration signal measured on the pilot by the Fourier transformer algorithms (FFT) to analyze transfer functions.

Coherence function of the impulse given by the impact hammer and accelerometer signal in frequency is calculated to indicate data quality. A coherence value close to the value of 1.0 indicates a good quality of data. The records IR amplitude transfer function is linear speed / force on the vertical axis (mobility), and frequency in Hz abscissa axis.

IR data can also be analyzed to determine the flexibility / rigidity of the element in its upper part and theoretical mobility to indicate the precise size of the defect.

An example of determining the change in cross-section of a pilot with the two methods SE / IR is shown in Figures 2 and 3.

ISSN 1582-3024

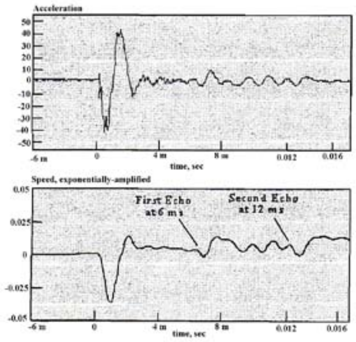

Figure 2. The result of the method for a fault located approximately 11 m from the top

Signal at the bottom of Figure 2 is obtained from the same data with the acceleration signal after being integrated and amplified exponentially. Echo times are at 6 and 12 ms, and determining defect depth are given below:

T =0.006 sec

Wave speed given by the compressive strength of the material (Vm) = 3658 m/sec

Similarly to equation (1) the depth of reflection is determined (Ar):

Ar = Vm * T/2 = 3658 * 0.006/2 = 11 m

Reflection has been identified as originating from a defect as reduction of section located approximately 11 m from the top of the item.

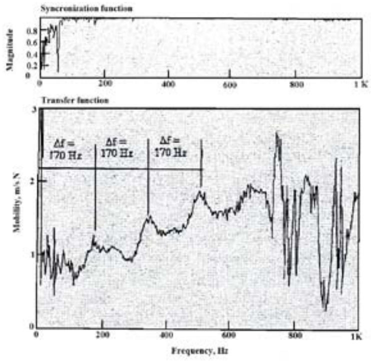

Figure 3. Result of IR method for a fault located approximately 11 m from the top

If the coherence function varies around 1.0 follows that the records are of good quality. Signal at the bottom of Figure 3 is the mobility function used to obtain depth reflection based on the distance between resonance peaks.

The distance measured between the resonance peaks Δf = 170 Hz

ISSN 1582-3024

The speed of wave given by the material's compression resistance (Vm) = 3658 m/sec

Similarly to equation (5) the depth of reflection is determined (Ar):

$Ar = Vm / \Delta f * 2 = 3658/ 170*2 = 10{,}8$ m

Reflection is seen again as coming from an anomaly given by the reduction section located approximately 11 m from the top.

The results of these two test methods are consistent, reducing the section being detected as located at the same depth.

3. TESTING CONDITIONS

In order to conduct the test should be access to the top of the pilot.

Concrete from the top of it should be removed so that the testing to be done on dry concrete, uniform, with a surface finish, no crazing. No excavation is required around the tested pilot. Transducer must be fixed or attached to the top of the pilot upright. Depending on the requirements can be used hammers with bits of plastic of different weights. In most cases is recommended implementation of several measurements in different positions of the upper horizontal surface and then compared with each other. Number of positions depends on the gauge measuring the pilot.

Changing the position of the transducer and using a hammer incorporating a force transducer and interpretation of force and speed signals may indicate, in some cases, defects in the immediate vicinity of the upper part of the pilot.

Transmitted frequency range depends on the coupling between the accelerometer and the pilot area, which increases with increasing rigidity of the link.

Nature of impact is an important factor in quality of results. Therefore, the impact should be conducted in accordance with the demands of measurements, taking into account the estimated depth of foundation of the pilot and the best detection of defects.

Noise in the measurement data is most easily minimized by applying digital filtering procedures.

Friction with the terrain and poor quality of concrete are the biggest obstacles to successful testing of item's continuity and determination of foundation depth, due to pressure wave energy dissipation. Exponential amplification with respect to time can lead to overcome these problems, but only if the records contain information reflected in the bottom of the item.

For pilots with the same length, from the same project, one must use the same amplification factor. Amplification factors are often chosen so that the response is similar to the initial pulse amplitude.

4. DESCRIPTION OF TESTED WORK. ITEMS CONSIDERED

The passage goes over the motorway Bucharest - Brasov section Vlasiei Mill - Ploiesti and facilitates the continuity of village road between the villages Dimieni and Dascalu. Passage has 4 spans, 25.50 m long each, two over the highway and two side bands.

The carriageway width is of 7.00 m, has 2 lanes, and the edges are set to 1.00 m wide sidewalks and pedestrian railing. On the road edges are set deformable metal runners, pavement the bridge is of asphalt.

Bridge superstructure has as resistance elements 5 T-section beams, prestressed concrete, which are monoliths to the top plate with over concreting slab.

Infrastructures of the overpass are of two drowned abutments and three massive piers, the latter having rectangular bearings, a part of its in console. Piers are placed on massive concrete foundations and the abutments on round columns, extended from the foundation.

Foundations of the overpass consist of large diameter bored pilots (1200 mm), being both seated at abutments and the piles in two rows. Their number, on each type of foundation, may be seen in Figure 1. Useful lengths considered at the lower levels of foundations (equalization concretes) to the tops at piles and at the lower level of extension poles (which is the natural terrain) until the tops at abutments are 24.00 m.

Looking generally at the site of overpass, the foundation soil in the area of the foundations, considered at the lower levels of foundations has a stratification consisting of:

- brown plastic consistent clay with limestone nodules - about 13.3 m;
- sandy clay, brown - gray, plastic consistent - about 1.7 m;
- fine sand, slightly clayey saturated - about 6.7 m;
- plastic consistent alternation of sandy clay and brown plastic strong clay - about 2.3 m.

Elements examined by the echo-sonic logging method are three large diameter bored pilots (1200 mm) for the piles foundations P01, P02 and P03. Pilots have been constructed according to SR EN 1536:2004, by the drilling method, placing reinforcement and concreting under the bentonite mud, using appropriate equipment. Useful lengths designed to achieve bearing capacity is 24 m.

ISSN 1582-3024

Their arrangement in the horizontal plane, on the context of the construction is shown in Figure 4.

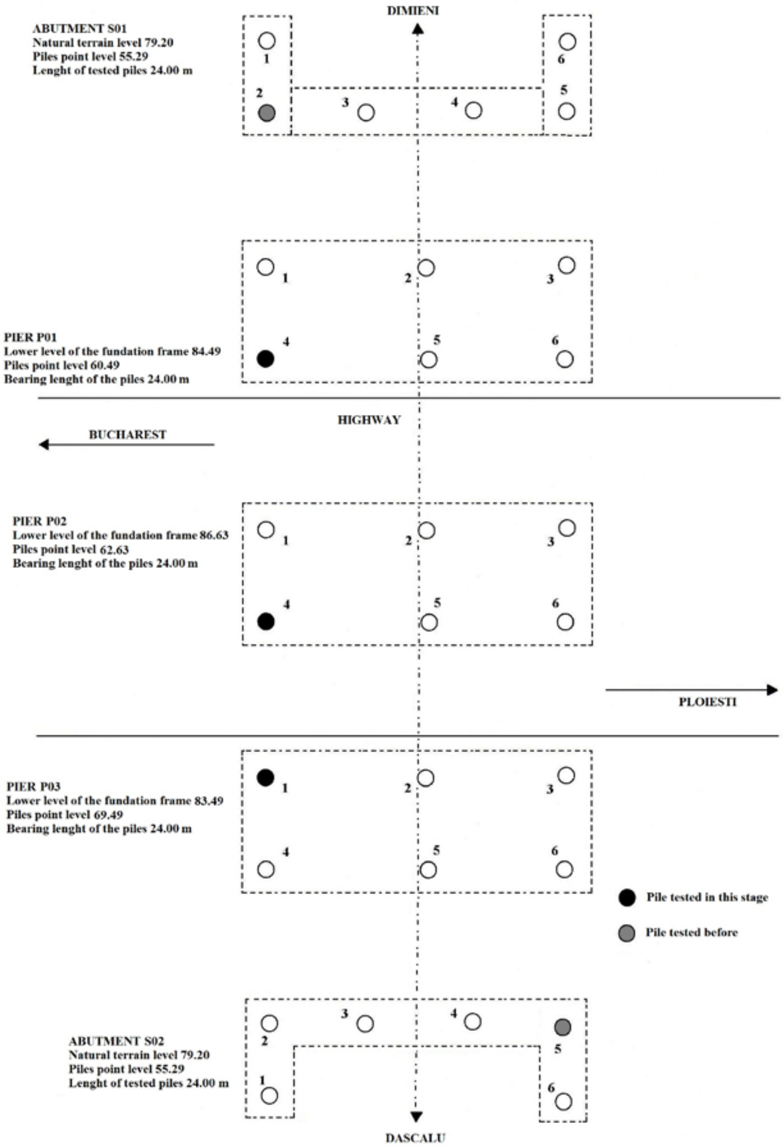

Figure 4. Plan the location of pilot test

Identification of pilots and characteristic data to achieve the measurements were made of existing quality documents and records on site (drawing project implementation, the recipe for concrete, concrete-drilling records, test results on the samples to determine the mechanical resistance) and are presented in Table 1.

Table 1. Particulars necessary to achieve measurement pilot

Symbol for pilot identification	Concreting data	Prescribed class	Type cement /sqm	Max. grain aggregate mm	Nature of stone	Pouring concrete	Specific weight kg/sqm	Average speed of sonic wave m/s	Concreting type for elements	Testing date
P01.4 P02.4 P03.1	12.08.2009 11.08.2009 18.08.2009	C 25/30	II B-M (S-V) 32,5 R /400	31	River	earth	2370	4200	under bentonite mud	05 Oct. 2009

Test equipment used ESAME TRAVELER - ESA Messtechnik Germany is composed of a signal conditioning module containing a analog to digital converter on 12 bit, 50kHz sampling frequency and duration of the registration of more than 30 ms and 3 accelerometers weighing 50 g, time constant of 0.5 seconds and resonant frequency of 30 kHz.

Figure 5. Test equipment

Recording of signals is performed on a laptop and software used was EE-SOFT-32.

Working stages of testing techniques are:

- identifying the position of pilots in the work and identify their notations, including notations of determination tests,
- Selection and plotting the points of impact and accelerometers positioning points;
- Preparing the surface for attaching accelerometers transducers 50 mm in diameter with a surface correction with an abrasive stone to a depth of 4 mm;
- Surface cleaning;
- Connecting the accelerometer transducers to measuring device;

- Attaching the transducers on the concrete surface with a poxiline film;
- Verification and calibration of recording achievement;
- Achievement of impact blows and data acquisition for 10... 20 shots at each point and record them on a laptop;
- Signal processing to obtain graphs for elastic wave velocity variation versus time (amplification, filtering, average).

Figure 6. Pilot testing P01.4

For each pilot, maximum length is identified starting from the lower rate of foundation until the peak detected by echo-sonic logging compared with the projected length, and is presented in Table 2.

Table 2. Test results

No.	Pilot identification	Diameter of the pilot [D]mm	Designed length for bearing capacity M	Estimated length integrity obtained by applied echo-sonic method Precision ±5%	Observations
1	P01.4	1200	24,00	23,90	-
2	P02.4			23,94	
3	P03.1			23,89	

Graphs from data acquisition program from working with EE-SOFT-32, for an average speed of the wave of 4100 m/s ±5%, according to type of concrete used and age are shown in Figure 7.

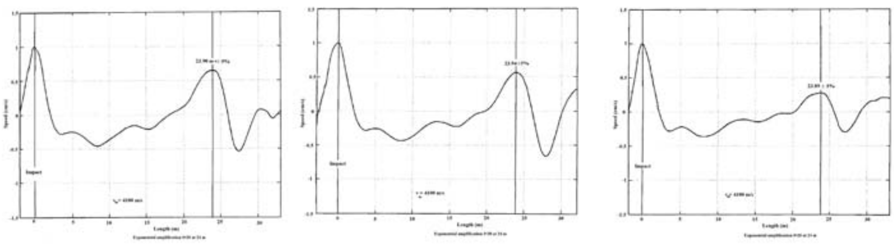

Figure 7. Speed-length charts for the three tested pilots

5. CONCLUSIONS

Following the results obtained by testing the pilots having symbols P01.4, P02.4 and P03.1, the foundations of the piles for Highway Bucharest - Brasov sector Bucharest - Ploiesti, Section 1, km 0.000 to 19.500, passage over highway which facilitates continuity of village road between the villages and Dascalu Dimieni the following may be observed:

1. Analyzing the impedance curves, between the areas of impact and the estimated peak detection, one may finds no sudden changes of impedance characteristic for a bottleneck or swelling of concrete in piles.

2. Analyzing lengths obtained from tests, and based on table 2 and given the estimated deviation of +/- 5%, one may say that they contain differences with height design value falling within the deviation allowed.

3. In conclusion, one may consider that test pilots were executed under the provisions of the design regarding the foundation, and / or useful length determined by the project. Also the condition of integrity is satisfied, meaning that concrete in its bodies is continuous and does not present variations of sections, in particular bottlenecks, interruptions or inclusions of other materials which could affect the bearing capacity.

References

1. Justification Note for Government Decision no.507 dated 19 April 2006 to approve technical-economical indicators for investment objective „Bucharest-Brasov Motorway km 0+000 – 173+300", Monitorul Oficial no. 360 dated 21 April 2006
2. SR EN 1997-1:2004 Eurocod 7: Geotechnical Design. Part 1: General rules
3. SR EN 1536:2004 Execution of special geotechnical works. Bored pilots
4. SR ASTM D 5882:2005 Standardized method for determining the integrity of pilots by small deformations tests
5. ASTM D 5882 -2007 Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations
6. Ştefan VICOLEANU, eng. – Report regarding integrity tests of large diameter bored pilots P01, P02, P03 using the echo-sonic method for the overpass of Bucharest-Brasov motorway at km 16+580, October 2009
7. Alexander TAFFE, Christoph GEHLEN - Methodology for the validation of NDT-CE methods using transit time measurement Non-Destructive Testing in Civil Engineering Nantes, France, June 30th – July 3rd, 2009
8. WHITE B., NAGY M., ALLIN, R. - Comparing cross-hole sonic logging and low-strain integrity testing results, 8th International Conference on the Application of Stress Wave Theory to Piles, Lisbon, 2008
9. Mohamad H. HUSSEIN, Garland LIKINS - Deep Foundations Quality Control and Quality Assurance Testing Methods, Florida Engineering Society Journal, March 2005
10. Ernst NIEDERLEITHINGER, Alexander TAFFE - Concept for reference pile testing sites for the development and improvement of NDT-CE, Non-Destructive Testing in Civil Engineering, Berlin, Germany September 16-19, 2003

ISSN 1582-3024

11. Jaroslaw RYBAK, Lukasz SADOWSKI, Krzysztof SCHABOWICZ - Non-destructive impulse response s'mash method for concrete pile testing, Defektoskopie 2008, Czech, Brno, 4 – 6 November 2008
12. Daniel AMBROSINI, Javier EZEBERRY- Long piles integrity trough impact echo technique, MECOM 2005 – VIII Congreso Argentino de Mecánica Computacional, Buenos Aires, Argentina, Noviembre 2005
13. Mark Johnson, Frank Rausche – Low strain testing of piles utilizing two acceleration signals, 5^{th} International Conference on the application of stress-wave theory to piles, Orlando, Florida, SUA, September 11-13, 1996