OSNOVE ISPITIVANJA INTEGRITETA ŠIPOVA S PRIMERIMA IZ PRAKSE

BASIS OF PILE INTEGRITY TESTING WITH FEW CASE HISTORIES

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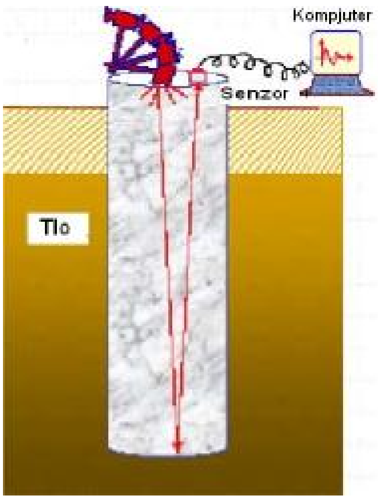
1 UVOD

Kada su u pitanju duboko fundirane temeljne konstrukcije, opterećenje se najčešće prenosi preko pobijenih prefabrikovanih šipova ili preko šipova izvedenih direktno u tlo. Tokom ugradnje, prefabrikovani šipovi mogu da se oštete ili polome, što je rezultat delovanja visokih napona tokom ugradnje. Šipovi formirani direktno u tlo mogu da pretrpe smanjenje ili proširenje poprečnog preseka, šupljine, inkluzije materijala različitih fizičkih svojstava itd. Prefabrikovani šipovi i šipovi formirani direktno u tlo mogu da se oštete i nakon ugrađivanja, nepažljivim rukovanjem građevinskim mašinama. Događaji koji dovode do formiranja defekata u šipu dati su u [8].

1 INTRODUCTION

In deeply founded structures, the loading is mostly transmitted through the driven precast piles or cast-in-situ piles. During installation, precast piles may be damaged or broken as the result of the high stresses that exist during the installation process. In cast-in-place piles, the following can appear: a reduction or expansion of the cross-sectional area, cavities, inclusion of materials of various physical properties, etc. Precast and cast-in-place piles may be damaged also after their installation as the result of misuse of construction machinery. A comprehensive list of events, each of which can lead to the formation of a defect in a pile (either cast-in-situ or driven) is presented by [8].



Slika 1: Postupak ispitivanja
Figure 1: Test procedure

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Kako bi se stekao uvid u gore pomenute neregularnosti, potrebno je izraditi program kontrole kvaliteta šipova. Da bi krajnji produkt – u ovom slučaju šip – imao zadovoljavajući kvalitet, potrebna je saradnja između projektanta, izvođača, nadzora i inženjera geotehnike angažovanih za kontrolu kvaliteta izvedenih šipova [6].

Postoje različite nedestruktivne metode za kontrolu kvaliteta izvedenih šipova. Najčešće se primenjuje zvučna eho (*sonic echo*) i impulsna metoda (*impuls response*), zatim *cross-hole* metoda, a vrlo retko i radioaktivna metoda [5]. U ovom radu biće razmatrana zvučna eho metoda (SIT– *Sonic Integrity Test*). Naziv ukazuje na to da se ispitivanje sprovodi u domenu zvučnih frekvencija.

2 OSNOVNI PRINCIPI ZVUČNE (SIT) METODE

Tokom poslednjih nekoliko decenija, zvučna metoda izdvojila se kao jeftina i brza metoda kojom se za nekoliko minuta može ispitati dati šip. Da bi se test sproveo, potrebno je da se postavi senzor (obično akcelerometar) na vrh šipa i izazove kompresioni talas udarom o vrh šipa ručnim čekićem – slika 1. Kompresioni talas se prostire kroz šip i reflektuje se od baze šipa (kontakt betona i prirodne sredine). Reflektovani talas može biti ili kompresioni ili tenzioni, zavisno od odnosa krutosti betona i prirodne sredine. Ukoliko postoje promene poprečnog preseka ili pukotine, one takođe izazivaju refleksiju – slika 2. Akcelerometar registruje ubrzanje glave šipa pri udaru, kao i svako sledeće ubrzanje izazvano refleksijom talasa unutar šipa, koji dostiže do njegovog vrha. Signal prikupljen akcelerometrom u analognoj formi se digitalizuje i integriše da bi se dobio zapis brzine (v) glave šipa. Tipičan zapis brzine (v) u vremenu (t) prikazan je na slici 2. Ovakav zapis zove se reflektogram i predstavlja osnovu za procenu integriteta šipa.

Teorijsko razmatranje talasa u čvrstoj sredini zavisi od preovlađujuće talasne dužine [9]. Ukoliko je talasna dužina veća ili jednaka prečniku šipa, problem postaje jednodimenzionalan, to jest važi teorija jednodimenzionalnog prostiranja naponskog talasa. To je uobičajeno za naponske talase izazvane udarom ručnog čekića kao kod zvučne metode. Kada je talasna dužina mala u poređenju s prečnikom šipa, problem postaje trodimenzionalan. To je karakteristično za ultrazvučna *cross-hole* ispitivanja. Osnovna jednačina koja daje vezu između brzine prostiranja naponskog talasa (c), talasne dužine (λ) i frekvencije (f) ima sledeći oblik:

In order to gain an insight into the above-mentioned irregularities, it is necessary to develop a programme for controlling the quality of piles. In order to satisfy the quality of the end product, i.e. a pile, it is necessary to ensure close cooperation between designers, contractors, supervisors and geotechnical engineers involved in the control of quality [6] of installed piles.

There are a variety of non-destructive methods for controlling the quality of piles. The most commonly used methods are the sonic echo test, the impulse response test, and the cross-hole method, while the radioactive [5] method is seldom used. This paper considers the sonic echo test (SIT) method. As indicated by its name, this method is based on the use of acoustic frequencies.

2 BASIC PRINCIPLES OF SONIC (SIT) METHODS

Over the past few decades the sonic method emerged as a cheap and quick method of testing the given pile in a few minutes. The test is conducted by placing the sensor (typically an accelerometer) onto the head of the pile and causing a compression stress wave by striking the pile head with a special hand-held hammer (Figure 1). The compression wave travels down along the pile shaft and it is reflected from the pile toe (the contact point of concrete and the surrounding soil). The reflected wave can be either tensile or compressive, depending on the stiffness ratio between concrete and the environment. Any changes in pile diameter or discontinuities will also cause reflection (Figure 2). Accelerometer records the pile head acceleration during blow as well as each succeeding acceleration caused by the reflection of waves within the pile that reaches to its head. Since the signal collected by the accelerometer is analogous, it needs to be converted into digital form and integrated in order to trace the velocity (v) of the pile head. A typical velocity (v) - time (t) trace is shown in Figure 2. This trace is called reflectogram and it is the basis for assessing the integrity of the pile.

The theoretical consideration of waves in a solid environment depends on the prevailing wavelength [9]. If the wavelength is longer or equal to the cross-sectional area of the pile, there is a one-dimensional problem, i.e. the theory of one-dimensional propagation of stress waves applies. This is typical for stress waves caused by the impact of a hand-held hammer, which is the case in sonic methods. When the wavelength is shorter than the cross-sectional area of the pile, the problem becomes three dimensional. This is the case in ultrasonic cross-hole testing. The basic equation for calculating the relationship between the stress wave speed (c), wavelength (λ) and frequency (f) is the following:

$$c = l * f \tag{1}$$

Ova jednačina omogućava da se odredi talasna dužina u trenutku testiranja na osnovu ostvarene frekvencije i pretpostavljene brzine (c).

U vremenu 2L/c, gde je **L** dužina šipa, a **c** brzina naponskog talasa kroz beton, talas se reflektuje i vrati do vrha šipa, gde ga registruje akcelerometar. Na taj način, dobija se podatak o dubini i mestu na kome postoji promena poprečnog preseka ili materijala u šipu. Refleksije nastaju na mestu promene impedanse šipa (Z). Karakteristike šipa koje definišu impedansu jesu

This equation allows for the determination of the wavelength on the basis of frequency and assumed velocity (c) at the time of testing.

At the time of 2L/c, where (L) is the pile length and (c) is the speed of stress wave propagation through the concrete, the wave is reflected back to the pile head, where it is recorded by the accelerometer. This is the method of obtaining data on the depth of the location where there is a change in the cross-sectional area of the pile or in its material. Reflections occur at the brzina talasa (c), modul elastičnosti betona (E) i površina poprečnog preseka (A), kako je prikazano u jednačini 2.

location of changes in pile impedance (Z). Pile impedance is defined by the following properties that define its wave velocity (c), modulus of elasticity of concrete (E) and the cross-sectional area (A), Equation 2:

$$z = \frac{EA}{c} \tag{2}$$

Na slici 2a prikazan je šip sa smanjenim poprečnim presekom na donjoj polovini i grafik zavisnosti brzine (v) u vremenu (t). Na slici 2b dat je šip, ali u ovom slučaju smanjenje poprečnog preseka je bliže vrhu šipa. Upoređenjem reflektograma, uočava se da što je promena impedanse (Z) bliža vrhu šipa, veći je broj refleksija, a samim tim reflektogram je složeniji za interpretaciju. Na kontaktu dve sredine različitih impedansi deo inicijalnog talasa se reflektuje. Amplituda reflektovanog talasa (Ar) zavisi od odnosa specifičnih impedansi i amplitude inicijalnog talasa (Ai) [10], jednačina 3.

Figure 2a shows the graph of dependence of velocity (v) in time (t) for a pile with a reduced cross-sectional area in its lower section. Figure 2b shows a pile with a reduced cross-sectional area closer to its head. When comparing the reflectograms, the number of reflections obviously increases when the change of impedance (Z) is closer to the pile head, making the interpretation of the reflectogram a more complex task. At the contact point of the two different environments, part of the initial wave is reflected. The amplitude of the reflected wave (Ar) depends on the ratio of specific impedances and the amplitude of the initial wave (Ai) [10], Equation 3:

$$Ar = \frac{z_2 - z_1}{z_1 + z_2} Ai \tag{3}$$

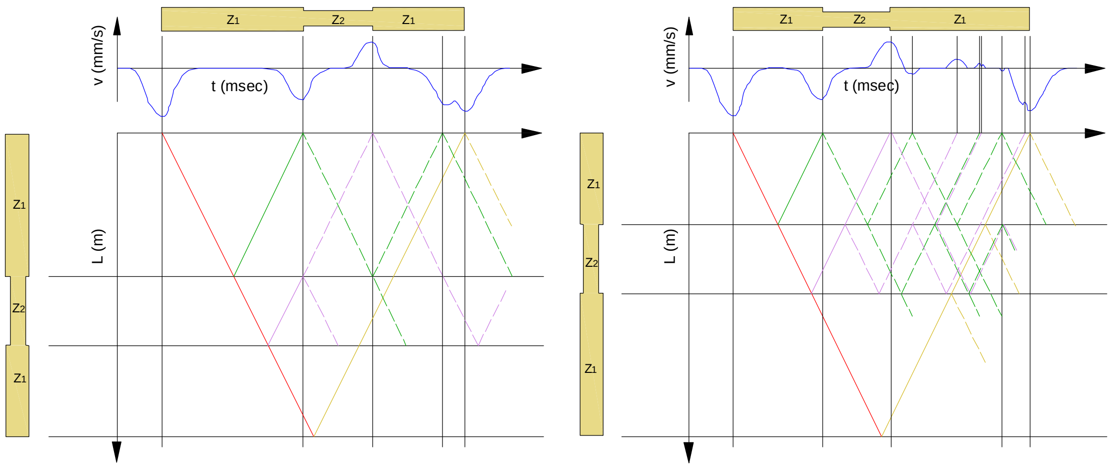
Na sličan način se može izračunati amplituda talasa koji nastavlja dalje kretanje kroz šip (At) preko jednačine 4.

The amplitude of the wave that continues further through the pile (At) can be calculated in a similar way, by Equation 4:

$$At = \frac{2z_2}{z_1 + z_2} Ai \tag{4}$$

Ove dve jednačine daju uvid u ponašanje talasa dok se kreće kroz šip proizvoljnog oblika. Kada je impedansa $Z_1 < Z_2$, talas se reflektuje sa istim znakom (kompresioni) kao inicijalni (npr. proširenje stabla šipa). Kada je $Z_1 > Z_2$, reflektovani talas menja znak (npr. suženje stabla šipa).

These two equations provide an insight into the behaviour of the wave as it propagates through an arbitrary shaped pile. When the impedance is $Z_1 < Z_2$, the wave is reflected with the same sign (compression) as the initial wave (e.g. increse in cross-section). When $Z_1 > Z_2$, the reflected wave changes its sign (e.g. decrese in cross-section).



Slika 2: Reflektogram i karakteristične linije šipa sa smanjenim poprečnim presekom : a) na donjoj polovini ($Z_2 < Z_1$) i b) na gornjoj polovini ($Z_2 < Z_1$).

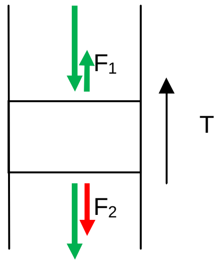
Figure 2: Reflectogram and the characteristic lines of a pile with a reduced cross-sectional area: a) lower section ($Z_2 < Z_1$) and b) upper section ($Z_2 < Z_1$)

3 UTICAJ TRENJA

U svim prethodnim analizama pretpostavljeno je da ne postoji trenje po omotaču šipa. Međutim, ta pretpostavka ne odgovara stvarnoj interakciji šipa i tla pri prolasku talasa kroz deo šipa. Pomeranje dela šipa angažuje trenje po njegovom omotaču [4]. Uticaj sile trenja (T), mobilisane kompresionim talasom, prikazan je na slici 3.

3 FRICTION EFFECTS

In all previous analyzes, no friction was assumed along the pile shaft. However, this assumption fails to correspond to the actual pile-soil interaction during the propagation of wave through a pile section. When a pile section is moved, it causes friction along its shaft [4]. The influence of friction force (T) that is mobilized by the compression wave is shown in Figure 3.



Slika 3: Uticaj sile trenja na talas koji se kreće nadole
Figure 3: Influence of the friction force on the downward moving wave

Sila trenja proizvodi dva talasa, reflektovani kompresioni (F_1) i tenzioni talas (F_2) koji nastavlja dalje jednaka po magnitudi T/2. S obzirom na to što je reflektovani talas istog tipa kao inicijalni, kompresioni talas izaziva refleksiju u vidu kompresionog talasa, odnosno trenje ima sličan efekat kao povećanje impedanse. S druge strane, komponenta F_2 se superponira sa inicijalnim talasom, a budući da je suprotnog znaka, rezultat je slabljenje (prigušivanje) signala. Ukupna energija talasa u šipu se smanjuje, a razlika se prenosi u okolnu sredinu.

Može se dokazati tvrdnja da će, kada se šip optereti na jednom kraju nekom dinamičkom silom, usled uticaja trenja, na drugi kraj sila stići oslabljena po eksponencijalnom zakonu (e^{-k}), gde u eksponentu (k) figuriše odnos dužine (L) i prečnika (D) šipa. Ovo je naglašeno, jer mali porast L/D značajno slabi silu i brzinu koja dolazi na vrh šipa. Zato se primenjuje eksponencijalna amplifikacija signala kao kompenzacija za efekat slabljenja signala prilikom testiranja šipova. Ponašanje sistema šip-tlo pri dinamičkom opterećenju detaljno je analizirano u [4].

4 BRZINA TALASA KROZ BETON

Brzina talasa kroz beton data je sledećom jednačinom:

The friction force produces two waves, a reflected compressive (F_1) and tensile wave (F_2) which continues further and its magnitude is equal to T/2. Since the reflected wave is of the same type as the initial wave, the compression wave causes a reflection in the form of a compression wave, i.e. the effect of friction is similar to the effect of increased impedance. On the contrary, the F_2 component is superimposed with the initial wave, and given its opposite sign, this results with signal attenuation (damping). The total wave energy in the pile decreases, with the difference being transferred into the surrounding environment.

It can be proved that when the pile is loaded by a dynamic force at its one end, due to the influence of friction forces, when reaching the other end the force will be weakened according to the exponential law (e^{-k}), where the superscript (k) indicates the relationship between pile length (L) and diameter (D). This is emphasized because a small increase in L/D significantly weakens the force and the velocity that reaches the pile head. Therefore, the signal is exponentially amplified in order to compensate for the effect of signal attenuation during the pile testing. The behaviour of the pile-soil system under dynamic loading is analyzed in detail in [4].

4 STRESS WAVE SPEED THROUGH THE CONCRETE

The speed of wave through the concrete is given by the following equation

$$c = \sqrt{\frac{E}{r}} \tag{5}$$

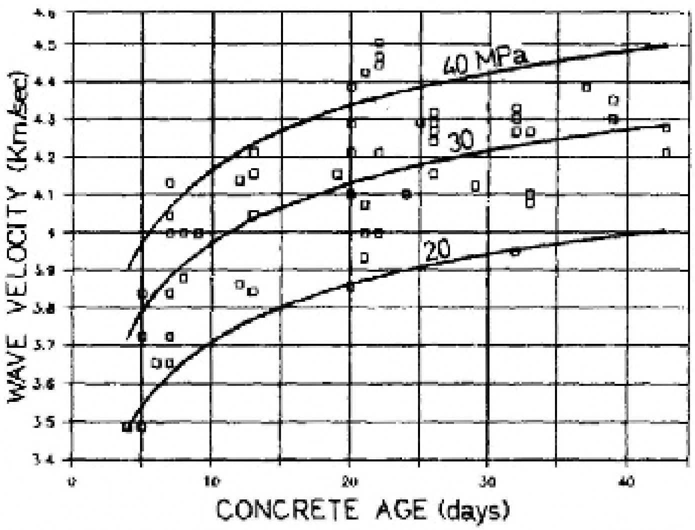
Iz jednačine 5 može se videti da brzina talasa (c) zavisi od modula elastičnosti (E) i gustine betona (ρ). Gustina se određuje u trenutku betoniranja i predstavlja konstantnu veličinu. Kada je u pitanju beton, gustina (ρ) obično iznosi 2400 kg/m^3. S druge strane, modul elastičnosti raste s povećanjem čvrstoće betona. Zato se

From Equation 5 it can be seen that the wave speed (c) depends on the modulus of elasticity (E) and the density of concrete (ρ). The density is determined at the time of concreting and it is a constant value. The density of concrete (ρ) is usually 2400 kg/m^3. On the other hand, the modulus of elasticity increases along with the i brzina talasa povećava s povećanjem starosti betona.

Na osnovu laboratorijskih ispitivanja uzoraka oblika kocke, prema [2] dobijena je zavisnost brzine (c) od starosti i klase betona koja je prikazana na slici 4. Očigledan je porast brzine sa starenjem betona. Brzine posle sedam dana nalaze se u rasponu od 3600 m/s do 4400 m/s. To znači da, ukoliko ne postoji informacija o brzini talasa (što je u praksi čest slučaj), korektna je pretpostavka 4000 m/s, pa zato očekivana greška u određivanju dužine šipa može da bude ±10%.

increase of the strength of concrete. Therefore, with the increasing age of concrete, the wave speed also increases.

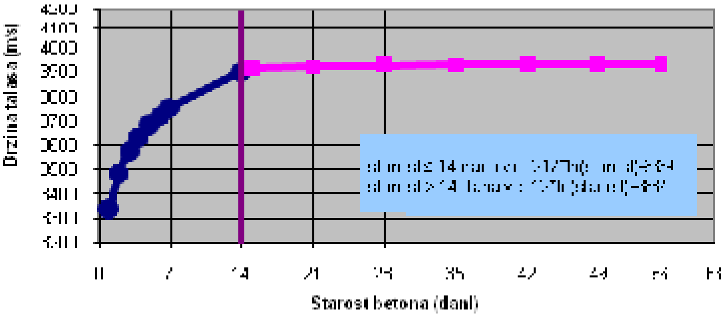
Based on laboratory tests performed on a cube, according to [2] the dependence of speed (c) on the age and strength of concrete has been obtained, which is shown in Figure 4. There is an obvious increase in velocity with age of the concrete. After seven days, speed range between 3600 and 4400 m/s. This means that with the lack of information on wave speed (which is often the case in practice), it should be assumed 4000 m/s, so that the expected error in determining the pile length may be ± 10%.



Slika 4: Brzina talasa u funkciji starosti i marke betona, prema [2].
Figure 4: Wave speed as a function of age and strength of concrete, according to [2]

Jednačine za proračun brzine talasa kroz beton, u zavisnosti od starosti, prikazane su na slici 5. Jednačine su izvedene na osnovu brojnih terenskih i laboratorijskih ispitivanja [7]. Slika 5 predstavlja grafički prikaz jednačina datih na slici. Vidi se nagli porast brzine do 14 dana, dok je posle značajno sporiji. Prema [7], nesigurnost u određivanju dužine jeste ±5% u zavisnosti od toga da li je brzina izmerena, procenjena ili dobijena iz korelacije sa čvrstoćom. Treba biti oprezan prilikom primene ovih rezultata, jer nisu opšteg karaktera i odnose se na betonsku mešavinu primenjenu u studiji. Međutim, opšti trend odgovara betonu koji se obično koristi za izradu bušenih šipova. Prema [3], navodi se da se, ukoliko se dobro proceni brzina talasa, pouzdana merenja dužine i položaja defekata mogu postići nakon deset dana od ugradnje betona.

Equations for calculating the wave speed through the concrete as a function of its age are shown in Figure 5. These equations are derived on the basis of numerous field and laboratory tests [7]. Figure 5 is a graphical representation of the equations given in the figure. It can be seen that up to the 14^{th} day there is a sharp increase in speed, while after that, it is much slower. According to [7], uncertainty in determining the length is ± 5%, depending on whether the speed is measured, estimated or obtained from the correlation with strength. One should be cautious when applying these results because they are not generalized – they are related to the concrete mixture which is applied in the study. However, the general tendency corresponds to concrete that is commonly used for making bored piles. In [3], it is stated that 10 days after installing the concrete, reliable measurements can be achieved regarding the length and position of defects if the wave speed is correctly assessed.



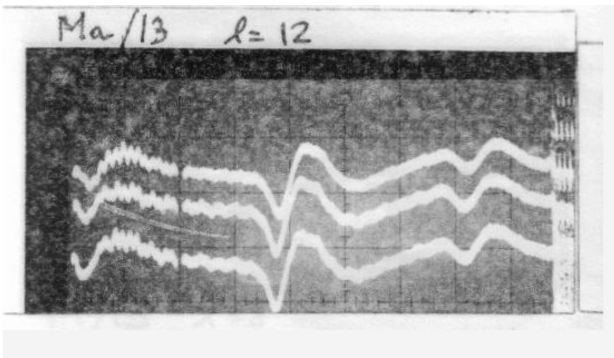
Slika 5: Zavisnost brzine talasa od starosti betona [7].
Figure 5: Dependence of wave speed on the age of concrete [7]

5 INTERPRETACIJA

Prva ispitivanja integriteta šipova sprovedena su pomoću osciloskopa i amplifikatora (slika 6), a bila su vrlo primitivna i ograničenih mogućnosti, bar za današnje standarde. Razvoj elektronike i računarske tehnike imao je snažan uticaj na savremene sisteme za ispitivanje. Interpretacija može biti kvalitativna i kvantitativna.

5 INTERPRETATION

The first tests regarding pile integrity were carried out using oscilloscope and amplifiers (Figure 6). They were primitive with limited capabilities, at least by today's standards. The development of electronics and computer technology made a profound influence on modern testing systems. Interpretation can be qualitative and quantitative as well.



Slika 6. Reflektogram prikazan na ekranu osciloskopa (preuzeto iz [1]).
Figure 6: Reflectogram displayed on an oscilloscope screen (taken from [1])

Kvalitativna interpretacija podrazumeva da se dobijeni reflektogram uporedi s karakterističnim reflektogramima šipova različitih oblika.

Kvantitativna interpretacija omogućava kvantifikovanje uočenih nepravilnosti u šipu. Kada je poznata raspodela trenja po omotaču šipa, može se nacrtati sintetički reflektogram korišćenjem odgovarajućih jednačina. Pojedini softveri omogućavaju da se dobije aproksimativno rešenje korišćenjem tehnike „poklapanja signala”. Ova tehnika sastoji se u sledećem:

– Prvi korak je dobijanje kompjuterskog modela korišćenjem projektovanih dimenzija šipa i podataka o okolnom tlu. To omogućava računanje teorijski očekivanog odgovora (signala) na udar čekića o glavu šipa. Tako dobijen teorijski signal upoređuje se s karakterističnim signalom (npr. prosečni signal na gradilištu).

– U drugom koraku, podaci o tlu se modifikuju sve dok se kompjuterski signal ne usaglasi s karakterističnim signalom što je više moguće. Time se dobija raspodela trenja po omotaču šipa.

Qualitative interpretation implies that the obtained reflectogram is compared with typical reflectograms of piles of various shapes.

Quantitative interpretation allows the quantification of perceived irregularities in the pile. When the distribution of friction along pile shaft is known, a synthetic reflectogram can be drawn by using the corresponding equations. Some software applications allow approximate solution by using the "signal matching" technique. This technique consists of the following:

– The first step is to obtain a computer model using the designed dimensions of the pile and the data on the surrounding soil. This allows the calculation of the theoretically expected response (signal) to the hammer blow on the pile head. This theoretical signal is then compared with the characteristic signal, e.g. the average signal on site.

– In the second step, data on the soil are modified until the point is reached where the computer signal match with the characteristic signal as much as possible. This results in distribution of friction along the pile shaft.

Korišćenjem raspodele trenja, dobijene u drugom koraku, kompjuterski model variranjem poprečnog profila šipa generiše signal koji se poklapa, što je više moguće, sa signalom razmatranog šipa.

Kao rezultat dobija se poprečni profil šipa, što nam omogućava uvid u promene poprečnog preseka, odnosno mesta promene impedanse šipa, kao i njihovo kvantifikovanje.

6 PRIMERI IZ PRAKSE

Institut za ispitivanje materijala IMS iz Beograda gotovo dve decenije bavi se ispitivanjem integriteta šipova primenom zvučne metode. Institut IMS raspolaže najsavremenijom opremom holandskog proizvođača „Profound", koji je vodeća kompanija za proizvodnju te vrste opreme u svetu (slika 7).

The computer model generates a signal which matches with the signal of the given pile as much as possible using the distribution of friction, which is obtained in the second step, by varying the cross-sectional area of the pile.

Consequently, the cross section profile of the pile is obtained, which allows getting an insight into changes in cross-sectional area, i.e. the location where the pile impedance is changed and the quantification of these changes.

6 CASE HISTORIES

The Institute for Testing Materials (IMS, Belgrade) has been almost two decades involved in studying the integrity of piles using a sonic method (SIT – Sonic integrity test). The IMS Institute is equipped with the latest equipment of the Dutch manufacturer "Profound".

Slika 7: Savremena oprema SIT^{pro} za ispitivanje šipova u vlasništvu Instituta IMS.
Figure 7: The modern SIT^{pro} pile testing equipment owned by the IMS Institute

Pre postavljanja senzora, potrebno je pripremiti šip za testiranje. Priprema podrazumeva da je omogućen slobodan pristup glavi šipa uz uslov da izložen beton bude dobrog kvaliteta, bez ostataka tla, vode ili labavog betona na vrhu šipa. To je osnovni preduslov za uspešno ispitivanje.

Na slikama koje prate dalji tekst prikazani su rezultati dobijeni ispitivanjem šipova na nekoliko gradilišta u našoj zemlji. Uglavnom je reč o bušenim šipovima s kontinualnim zacevljenjem bušotine. Sva prikazana ispitivanja izvršio je Institut IMS u protekle dve godine.

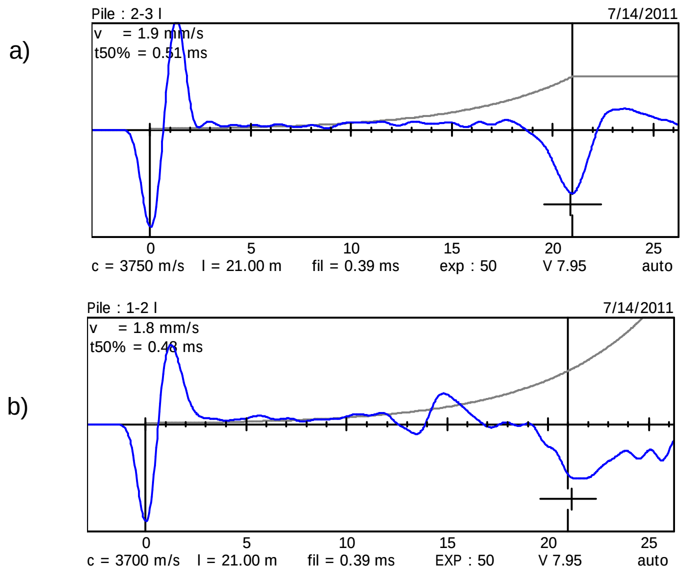
Primer 1. Na slici 8 prikazani su reflektogrami dobijeni ispitivanjem bušenih šipova (s kontinualnim zacevljenjem bušotine) prečnika 1200 mm, dužine 21 m. Reflektogram na slici 8a ukazuje na šip koji ima ujednačen poprečni presek i kvalitet betona, dok reflektogram prikazan na slici 8b ukazuje na to da postoji promena impedanse šipa na dubini oko 13.5 m i 15.5 m. Takav signal ukazuje na suženje u stablu šipa. Pored pomenutog šipa, još nekoliko šipova na istom gradilištu pokazalo je suženje na približno istim dubinama. U takvoj situaciji, potrebno je analizirati geološki sastav, s obzirom na to što tla različite krutosti mogu da izazovu

Before placing the sensor, it is necessary to prepare the pile for testing. Preparation means to allow free access to the pile head, provided that the exposed concrete is of good quality, free of soil, water or loose concrete on the pile head. This is the basic prerequisite for successful testing.

The pictures accompanying the following text illustrate the results obtained for piles at several construction sites in the country. These are mostly bored piles with the borehole being continuously tubed. All the presented tests are performed by the IMS Institute during the past two years.

Case 1. Figure 8 shows the reflectograms obtained for bored piles (with the borehole being continuously tubed) of 1200 mm diameter and 21 m length. The reflectogram in Figure 8a indicates a pile with a uniform cross-sectional area and quality of concrete, while the reflectogram in Figure 8b indicates that there are changes in impedance of a pile at depths of about 13.5 m and 15.5 m. This signal indicates a narrowing in the pile shaft. In addition to the aforementioned pile, a few other piles on the same construction site have indicated a narrowing at approximately same depth. In this iste refleksije, kao i promena kvaliteta betona ili suženje u stablu šipa. Budući da većina šipova na ovoj lokaciji ima ujednačen poprečni presek, geološki sastav tla je eliminisan kao mogući uzrok neregularnosti. Na osnovu razgovora sa izvođačem i nadzornim organom, pretpostavlja se da je posledica suženja upadanje okolnog tla u bušotinu prilikom izvlačenja bušaćih cevi u trenutku betoniranja. Ovakva pojava nije neuobičajena kada su u pitanju bušeni šipovi, čega treba da budu svesni svi, a pogotovo izvođači.

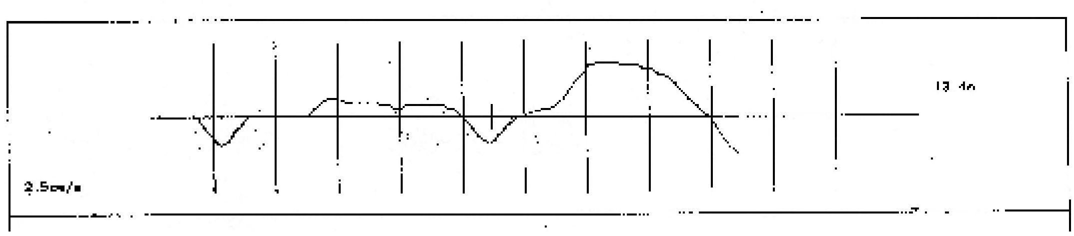
situation, it is necessary to analyze the geological structure of the soil; given that soils of varying stiffness can cause the same reflections as do the changes in the quality of concrete or the narrowing of the shaft. Given that most piles at this location have uniform cross-sectional area, the geological composition of the soil has been eliminated as a possible cause of the irregularities. Based on the interview with the contractor and supervisor, it is assumed that piles were narrowed as a consequence of the surrounding soil falling into the bore when the drilling pipes were drawn out in the moment of casting the concrete. This phenomenon is common for bored piles, and all should be aware of it, especially the contractors.



Slika 8: Reflektogrami: a) normalan šip i b) šip sa suženjem od 13.5 m do 15.5 m.
Figure 8: Reflectograms: a) normal pile and b) narrowed pile at the depth of 13.5 m and 15.5 m

Primer 2. Na slici 9 prikazan je reflektogram dobijen ispitivanjem šipa projektovane dužine 21.3 m. S reflektograma se vidi da postoji prekid u stablu šipa na dubini 13.4 m. Na toj dubini kompresioni inicijalni talas se u potpunosti reflektuje, menja znak i u vidu tenzionog talasa se vraća na površinu gde ga registruje akcelerometar. Na mestu prekida reflektogram je usmeren nadole (istog smera kao inicijalni talas), što ukazuje na tenzioni talas. Kasnije je utvrđeno da je prekid posledica petodnevnog prekida u betoniranju. Napominje se da ocena integriteta ispod mesta prekida nije moguća.

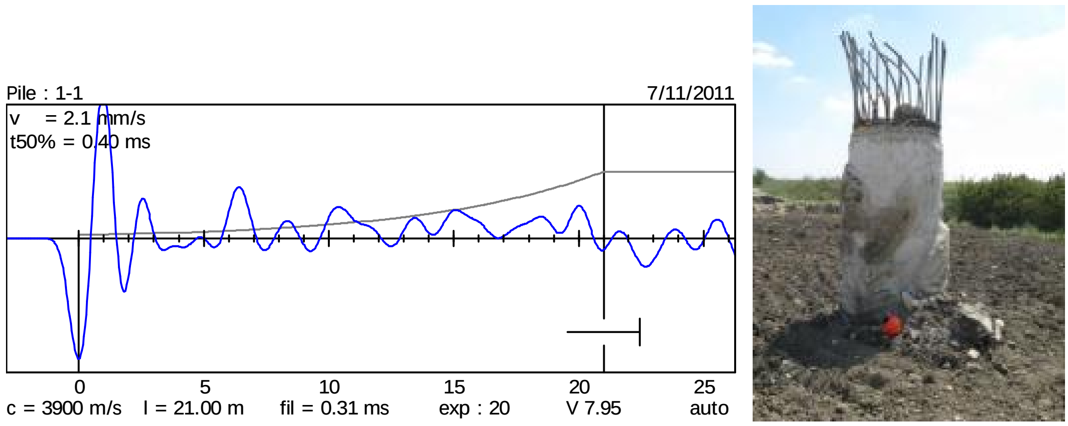
Case 2. Figure 9 shows the reflectogram obtained by examining a pile of designed length of 21.3 m. As indicated by the reflectogram, there is a discontinuity in the pile shaft at the depth of 13.4 m. At this depth, the initial compression wave is totally reflected, changed its sign and returns to the surface in the form of tensile wave where it is registered by the accelerometer. At the location of the discontinuity, the reflectogram is directed downwards (in the same direction as the initial wave), indicating a tensile wave. As later established, the discontinuity has resulted from a five-day interruption in concreting. It was noted that the assessment of integrity below the discontinuity was not possible.



Slika 9: Prekid u telu šipa na 13.4 m; projektovana dužina šipa iznosi 21.3 m.
Figure 9: Discontinuity in the pile body at the depth of 13.4 m. The designed length of the pile was 21.3 m.

Primer 3. Slika 10a prikazuje reflektogram složene talasaste forme bez odziva od baze šipa. Glavni uzrok ovakvog reflektograma jeste beton lošeg kvaliteta na dužini oko 2m od vrha šipa, što je potvrđeno iskopom tla oko šipa (slika 10b). U toku testiranja nije bilo moguće izazvati udarac koji ima talasnu dužinu veću od prečnika šipa (zbog male brzine prostiranja naponskog talasa), što predstavlja potreban uslov da bi se sprovela ispitivanja zvučnom metodom. U fazi izvođenja naglavne grede, beton slabijeg kvaliteta je uklonjen i zamenjen kvalitetnijim betonom.

Case 3. Figure 10a shows a reflectogram of complex wavy form without a response from the pile toe. The main cause of this reflectogram is a concrete of poor quality at the depth of about 2 m from the pile head. This was confirmed by excavating the soil around the pile (Figure 10b). During the test it was impossible to cause a blow with the wavelength longer than the pile diameter (due to the low propagation speed of the stress wave), which is a minimum condition for testing by the SIT method. In the stage of installing the capping beam, the low quality concrete was removed and replaced with higher quality concrete.



a) b)

Slika 10: Loš kvalitet betona pri vrhu šipa: a) reflektogram i b) otkriven šip.
Figure 10: Poor quality concrete at the pile top: a) reflectogram b) the exposed pile

7 OGRANIČENJA

Zvučnom metodom mogu da se uoče mnoge vrste defekata, ali postoje i oni defekti koji se ne mogu uočiti. To su prema [1]:

1. Male promene poprečnog preseka.
2. Postepene promene poprečnog preseka.
3. Promene impedanse na maloj dužini po osi šipa.
4. Mala odstupanja dužine u odnosu na projektovanu dužinu.
5. Pojave ispod potpunog prekida ili znatne promene impedanse (1:2).
6. Debljina odlomaka ispod baze šipa.
7. Odstupanja od prave linije i od vertikale.
8. Nosivost šipa.
9. Refleksije od baze šipa kada je L/D > 20 u tvrdom tlu i kada je L/D > 60 u mekom tlu.

Samo ukoliko smo svesni ovih ograničenja, možemo u potpunosti da iskoristimo zvučnu metodu za kontrolu kvaliteta šipova.

7 LIMITATIONS

The sonic method (SIT – Sonic Integrity Test) is suitable for detecting many types of defects, but there are also defects that cannot be detected. According to [1], they are the following:

1. Small changes in the cross-sectional area
2. Gradual changes in the cross-sectional area.
3. Changes of impedance along a short section parallel to the pile axis.
4. Small deviations from the designed length.
5. Changes beneath a total discontinuity or substantial changes in impedance (1:2).
6. The thickness of debris under the pile toe.
7. Deviations from a straight line and from the vertical.
8. The pile's bearing capacity.
9. Reflections from the pile toe when L/D > 20 in stiff soil, and when L/D > 60 in soft soil.

The full advantage of a sonic method (SIT – Sonic Integrity Test) for controlling the quality of piles can be taken only if we are aware of the above limitations.

8 ZAKLJUČAK

Šipovi se izvode u potpunom „mraku" i jedini uvid u kvalitet izvedenog šipa moguć je primenom dodatnih ispitivanja. Najpopularnija je zvučna (eho) metoda (SIT – *Sonic Integrity Test*), prikazana u ovom radu, kojom se može ispitati veliki broj šipova za kratko vreme.

Kada je u pitanju primena zvučne metode, bitna je pretpostavka o brzini prostiranja naponskog talasa kroz beton, jer je dužina šipa direktno proporcionalna toj brzini.

Poznavanjem mogućnosti, odnosno ograničenja navedene metode i principa na kojima se ona zasniva, moguće je otkriti defekte u šipu koji bi ugrozili bezbednost buduće konstrukcije. Prikazani primeri iz prakse ukazuju na greške koje nastaju pri izvođenju šipova i na značaj ove brze i jeftine metode u proceni kvaliteta izvedenih šipova.

8 CONCLUSION

The process of installing the piles unfolds in a complete "darkness" and the only way of getting an insight into their quality is by using additional tests. The sonic (echo) method (SIT – Sonic Integrity Test), which is presented in this paper, is the most popular and it allows the examination of large number of piles in a short time.

The assumption about the stress wave speed through the concrete is important in the application of the sonic (SIT) method, as the pile length is directly proportional to this speed.

It is possible to detect the defects in piles which would endanged the safety of the future structure by knowing the capabilities and limitations of the SIT method and its basic principles. The above practical examples have indicated the errors that occur during the installation of piles, as well as the importance of this fast and inexpensive method in evaluating the quality of installed piles.

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REZIME

OSNOVE ISPITIVANJA INTEGRITETA ŠIPOVA S PRIMERIMA IZ PRAKSE

Dušan BERISAVLJEVIĆ
Nenad ŠUŠIĆ

U poslednjih nekoliko godina, ispitivanje integriteta ugrađenih šipova postalo je veoma popularno na gradilištima u našoj zemlji. Pri tom, posebno mesto zauzima zvučna metoda, *„Sonic Integrity Test*" kao pouzdana, jeftina i vremenski malo zahtevna, a namenjena ispitivanju kvaliteta izvedenih šipova. U radu su prikazane osnove metode, teorijske postavke i nekoliko primera iz naše prakse.

Ključne reči: SIT, integritet, šip, signal.

SUMMARY

BASIS OF PILE INTEGRITY TESTING WITH FEW CASE HISTORIES

Dusan BERISAVLJEVIC
Nenad SUSIC

In recent years pile integrity testing have gained great popularity on sites all over the country. Special place among other methods belong to acoustic „Sonic Integrity Test" method which is reliable, inexpensive and little time consuming. This paper presents discussion on basis, theoretical aspects and few case histories.

Key Words: SIT, integrity, pile, signal.