Fourth International Conference on

Case Histories in Geotechnical Engineering

March 8 – 12, 1998, St. Louis, Missouri, USA

Editor : Shamsher Prakash

Sonic integrity test on piles founded in Bangkok subsoil – Signal characteristics and their interpretations

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Proceedings: Fourth International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, March 9-12, 1988.

SONIC INTEGRITY TEST ON PILES FOUNDED IN BANGKOK SUBSOIL SIGNAL CHARACTERISTICS AND THEIR INTERPRETATIONS

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Paper No. 11.02

ABSTRACT

Sonic integrity testing is a common method used to test the integrity of piles in Bangkok. An acoustic technique equipped with computer software, developed by TNO, PDI, IFCO, etc., is commonly used to test the piles. This paper presents the signal characteristics and their interpretations from sonic integrity test performed on mainly bored piles varying in length, size, construction method and founded soil strata. Toe reflection of small bored piles (diameter of 0.35m to 0.60m) constructed in Bangkok subsoil can be observed for pile length of up to 20m to 24m . Beyond 35m below the ground , visibility of toe reflection is uncommon for large bored piles (diameter of 0.80m and larger). Commonly predicted defects and frequency of occurrences are tabulated. Data sets have been selected from the Data Bank of a foundations specialists' organization to which the authors are associated with. Recently completed and current projects in Bangkok have been selected so that the data set could be well represented by over 8000 piles. 285 piles (3.3%) out of 8,689 piles have been interpreted for poor concrete or inclusions, cracks and size reduction. Among these, cracks contribute the major portion (2.2% or 194 piles). Cracks are mainly induced by either improper excavation adjacent to the piles or trimming the pile head by ill fated ways. Small diameter piles are the most suffered by cracks. Prominent sectional variations have been indicated by the signals at depth where temporary casing ends. Intermittent variations also are common at the interface of soft clay and medium to stiff clay layers.

KEYWORDS

Integrity, Sonic signal, Toe reflection, Pile impedance, Discontinuity

INTRODUCTION

Recent economic growth is being embraced by high-rise buildings in Bangkok, the city of Thailand, supplemented by other fast developing structures such as elevated highways and railways, bridges etc. As the Bangkok subsoil suffers a lot of constraints especially by the presence of thick soft clay on the top, almost every structure relies on pile foundation. Tens of thousands of piles are being constructed and tested annually in this city. For old structures, short friction piles (6-8m long) floating in the soft clay layer were commonly used. In modern practice, driven concrete piles with tips extending to the first sand layer or to stiff clay layer at a depth about 20-30m are normally employed for light to medium sized structures. For heavy structures or high-rise buildings deep large diameter (0.80m-1.5m) bored piles with tip extending to more than 45m are commonly used. Safety and overall stability of any finished structure highly depend on the foundation and assessing the quality of foundation is an inevitable aspect at the early stages of the structure. An acoustic technique equipped with computer softwares, developed by TNO, PDI, IFCO, etc., is commonly used to test the pile integrity.

TYPICAL SUBSOIL CONDITION IN BANGKOK

The Bangkok subsoil generally consists of 12-18m soft marine clay deposit underlain by medium to stiff clay. The medium dense to dense first silty fine sand is found below the stiff clay layer at depths 20m to 35m. The dense second sand layer occurs at about 50m depth. Between these sand layers, stiff to hard clay layers are present.

CONSTRUCTION METHOD

Two types of construction method, dry and wet process are commonly practiced in bored piling in Bangkok Soil.

Dry process uses steel temporary casing (about 15m in length) to protect the soft clay from caving in. The bore is drilled either auger or using bucket. For small piles, shells with drop weight is used to make the bore. Concrete is poured into borehole which is in dry condition after placing the reinforcement cage.

Wet process too normally uses steel temporary casing of 14-15m in length. A borehole is made by rotary method using auger or auger bucket under bentonite slurry. Concrete is poured with tremie method.

Dry process is employed mainly for small piles of 0.35m to 0.60m in diameter. Length of the piles are up to 25m and extends further if necessary, depending on subsoil condition, absence of sand layer with groundwater, etc.

For large bored piles of 0.80m to 1.50m in diameter, piles are constructed to depths of 30m to over 60m. Wet process is commonly used and piles are founded in sand layers.

Compressive cylindrical strength of concrete used in bored piles in Bangkok soil is in a range of 240-280 ksc (24-28 Mpa)

PRINCIPLES OF SONIC INTEGRITY TESTING

The test method is based on the time-domain, one dimensional wave theory. The compressive wave is propagated axially by the blow of hand-held impact device on to the pile head. The wave travels down along the pile shaft and reflects upward at the pile toe. In case where pile impedance variations occur due to changes in pile cross sectional area or properties of pile materials, or presence of discontinuities, part or whole of down ward traveling wave reflects at the impedance variations and returns to the pile top before the first reflection from the pile toe. The reflected wave is detected by an accelerometer mounted on the pile top. Signal traces of time-velocity are usually recorded. As piles are installed in the ground the reflected signal is usually influenced by shaft friction contributed by the surrounding soil layers.

The formulae commonly used in analysis of integrity are;

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

Where L is pile length, c is velocity of stress wave and T is travel time of the wave from pile top to toe and reflect back to the top.

Impedance of pile z (pile resistance to change in stress wave velocity) is given by

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

where A is cross-sectional area of piles and E is Young's Modulus of the pile material

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

from Equation (2) and (3)

$$z = \rho\, c.A \qquad (4)$$

where ρ is density of pile.

The length of pile is determined from the travel time of the reflected wave from the pile toe and the wave velocity in concrete. The velocity wave can be estimated from the concrete strength of piles or from the reference pile with known length. In the same way the location of discontinuities and irregularities in piles can be also determined. Equation (4) shows that the change in pile impedance could be due to variation in pile cross-sectional area or in concrete quality.

CHARACTERISTICS OF SONIC TEST SIGNAL IN BANGKOK SUBSOIL

Soil influence

Influence by different soil strata on signals have been observed in many cases. Stiff clay layer at depth 15-25m (undrained shear strength of 10-22 t/m^2.) influences prominently and higher degree of signal reflections have been observed in small bored piles than that of large bored piles. Figures 1 and 2 explain these conclusions.

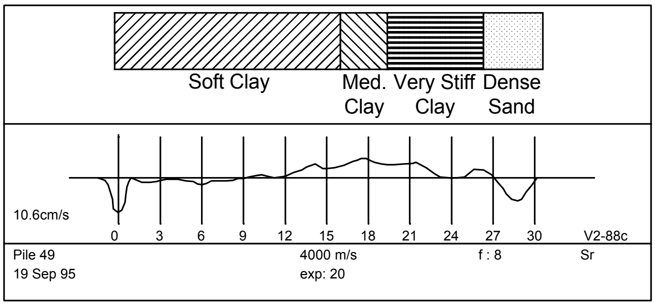

Fig. 1. Influence of soil friction on sonic signals (a pre-cast driven pile 0.40x0.40x25.0m in clay layers)

Toe reflections

Toe reflections are clear when the toe depth is 20-22m for piles of 0.35m-0.50m in diameter and up to 24m for 0.60m piles. In general, when pile length over diameter ratio (L/D) is within 40, toe reflections are clear and hence the pile length is predicted. However, for piles founded in depth deeper than 30-35m the toe reflection is uncommon as damping of signals is caused by deeper soil layers. Further, magnitude of toe reflection is prominent for larger piles compared to small piles with same length and constructed at same site. Figure 2 shows the signal characteristics of different size piles constructed just a few meters apart with same length.

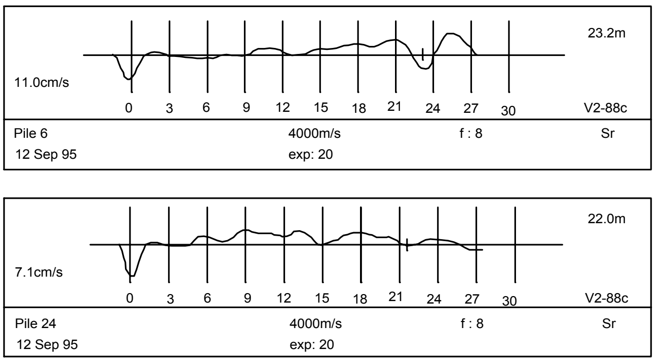

Fig. 2 Toe reflections from different pile sizes, pile no. 6 (ϕ 0.50m x 22.0m) and pile no. 24 (ϕ 0.35m x 22.0m)

In some cases, even though pile toe is extended beyond 35m in depth, the toe reflection can be observed in the test signals of toe grouted piles having L/D within 40.

Figure 3 is an example for such case where the bored piles were base grouted and of 40m in length (toe at 55m, trim level at -15m). However, it should be noted that these reflections are prominent only for few piles. Influence on toe reflection by grouted toe also depends on stiffness of the soil, underneath the toe, which has been grouted.

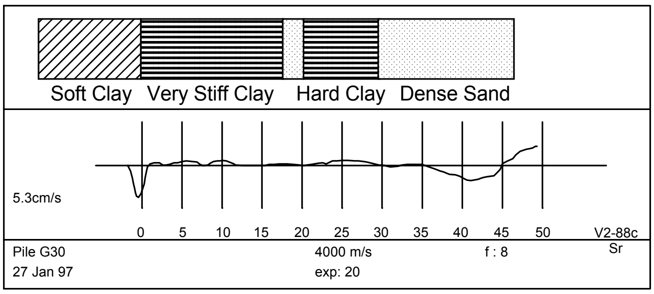

Fig. 3 Toe reflection observed from a toe grouted pile .(pileϕ 1.00m x 40.0m , cutoff –15.0m, toe depth 55.0m)

Size variations

Size variations interpreted by signals are often consistent with casting records and drilling monitoring results available.

Figure 4A and 4B show the comparison of borehole profiles and sonic test records.

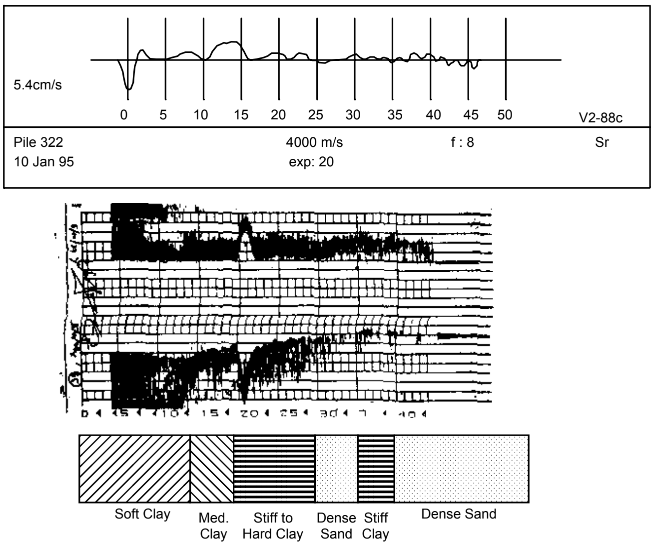

Fig 4A Size increase in pile shaft at 13m is shown by both sonic integrity test and drilling monitoring records. (Pileϕ 1.0m, cutoff –5.00m, toe depth –45m.)

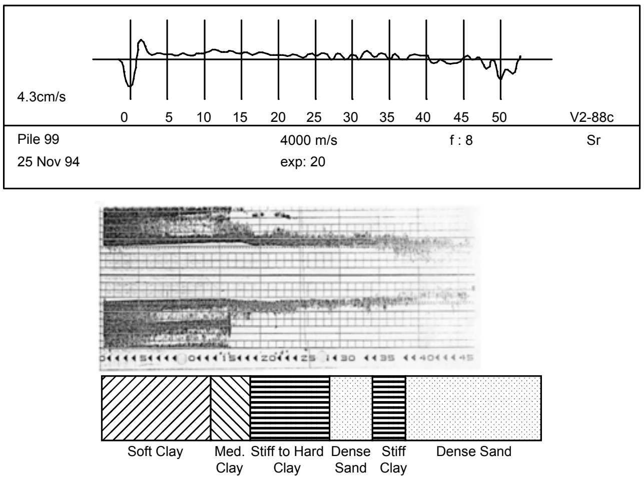

Fig 4B Uniform pile size along the pile shaft is shown by both drilling moitoring record and sonic integrity test record. (Pile ϕ0.80m, cutoff 3.0m, toe depth -45m.)

Common causes for size variations in bored piles are;

1. Effects from temporary casing
   - slight dimension changes of casing and bucket or auger
   - inadequate length to protect the soft clay
   - surface intact change at transition at the casing end
2. Delayed feeding of slurry and improper slurry level maintenance for wet process
3. Long time duration of maintaining open bore
4. Non continuous concrete pouring
5. Soil conditions such as inclusion of sand lenses in clay layers.

Figure 5 shows reduction of pile size at about 14m. A completed bored pile would have the size of outer casing at the top portion while the lower portion would be of bucket/auger size which is slightly less than the casing size. This size variation has been indicated by the signals at the transition zone. However dimensional variations by improper concrete slumping upon extracting the temporary casing and gradual dimensional changes at the transition zone are hardly indicated by the signal.

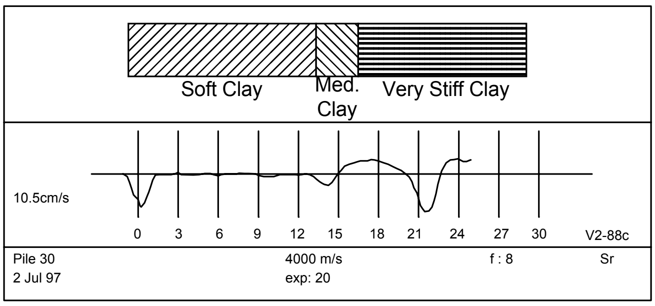

Fig. 5 Pile size decrease or change at 14m shown by the signal (Pile ϕ0.80m x 21.0m)

Figure 6 shows bored pile sections formed at the lower end of temporary casing. These bored piles were cast together with a steel column for construction of deep basements with diaphragm walls using top-down method. These piles were exposed when excavation reached to 15m below the ground level.

Fig. 6 The photograph illustrates the pile size changes caused by difference in diameter of temporary casing and auger used in pile construction.

The test signal in Fig. 7 shows size decrease caused by inadequate casing length used in soft clay layer. Such defect is found often in piles constructed by dry process using casings of inadequate length to protect the entire soft clay layer of varying thickness.

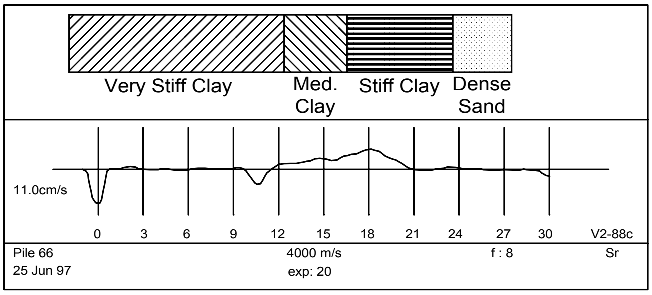

Fig. 7 The signal shows decrease in pile size at 10.6m (pile ϕ 0.35m x 26.0m)

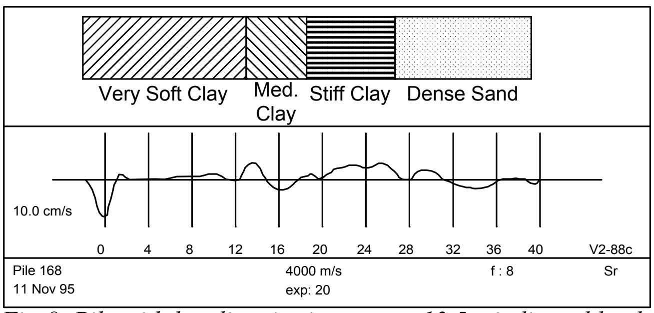

Fig. 8 Pile with localize size increase at13.5m indicated by the sonic signal, (pileϕ0.80m, cutoff 1.4m, toe depth 35.85m))

In contrast to the size reduction, caused by smaller auger/bucket size than the casing size, relative size increase also have been observed. Casting records for piles indicated in Fig. 8 noted about 30% over break of concrete volume.

Discontinuities/cracks

Common causes attributed for these are;
1. disruption in concrete pouring
2. contamination of concrete with bentonite slurry or soil
3. lifting up of insufficiently workable concrete or hardened concrete upon extracting the temporary casing

Figure 9A shows a discontinuity in pile shaft caused by disruption during concrete pouring. Concrete supply was interrupted by poor coordination between the piling contractor and concrete suppliers. By the time to resume the concreting the lower section has been hardened. The discontinuity found was later closed by coring and cement grouting. Figures 9A and 9B show the signal interpretation before and after closing the discontinuity.

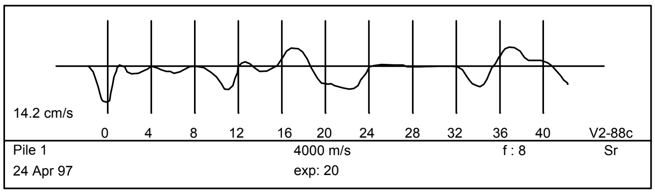

Fig 9A Sonic signal showing a discontinuity at 11.0m caused by interruption in concrete pouring(pile ϕ 0.80mx38.8m) and multiple reflections from the discontinuity.

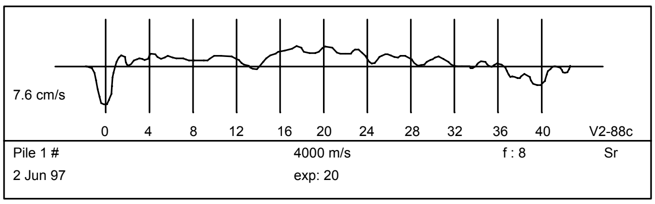

Fig. 9B Sonic integrity test shows the discontinuity at 11.0m has been closed by grouting.

Figures 10A and 10B show the characteristics of signals observed at a site where dry process was adopted. Many piles at this particular site were interpreted for poor integrity especially at the bottom portion. From the construction records it was noted that boring was done in water bearing sand layer without casing or bentonite slurry causing concrete contamination with water and/or segregation.

Further, static pile load test results indicate the test pile (Fig. 10B) failed well before designed maximum test load. Figure 10B also shows the joint between pile cap and pile.

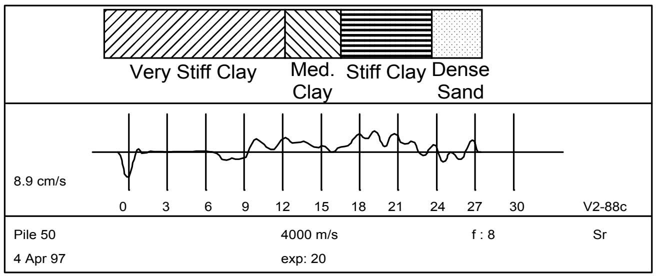

Fig. 10A Sonic test signal showing size decrease and or a discontinuity at 7.5-9.0m and poor quality pile section near the to (Pile 0.35m x 20.0m)

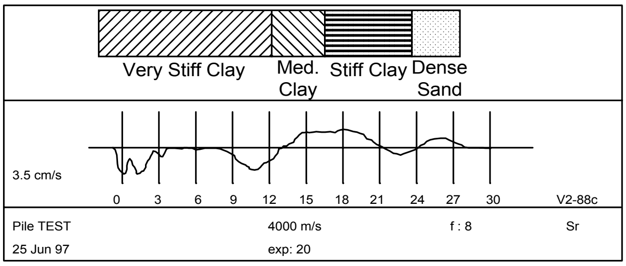

Fig. 10B Sonic signal on the failed test pile showing a construction joint between pile cap and pile top at 1.40m. Size decrease or a discontinuity is also indicated.

Figure 11A shows presence of poor quality concrete at the pile top due to contamination of concrete with bentonite slurry. Such defect is often found in piles with shallow cutoff level and hence adequate over cast length to have a sound concrete at cut off level, sometimes, cannot be made. Normally 1.0m to 2.0m over-casting of concrete is practiced.
After trimming back the pile top, sonic test was performed and the test signal indicates the sound integrity of the same (see Fig. 11B)

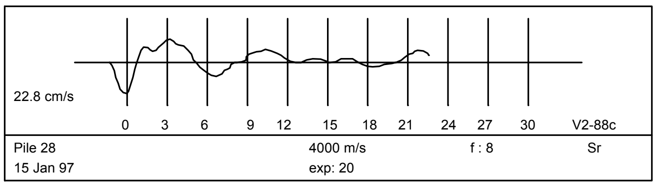

Fig. 11A The signal showing poor quality concrete at pile top section (Pile ϕ0.60m x 18.0m)

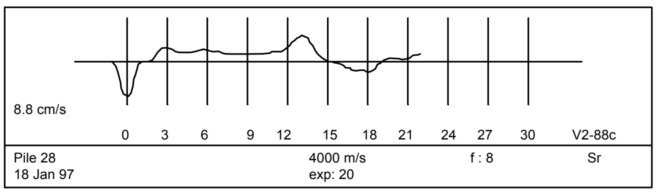

Fig. 11B The signal acquired after trimming top portion. The reflections from the lower part of the pile and toe become visible.

Physical pile damage due to excavation or improper chipping to trim level

Most discontinuities or cracks in bored piles after installation of piles can be caused by construction activities associated with basement excavation adjacent to them and improper trimming to design cut-off level.

The test signal in Fig. 12 shows a crack or discontinuity in the pile caused by soil movements occurred by adjacent excavation work.

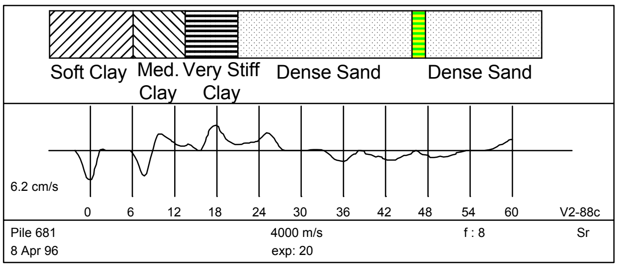

Fig. 12 Sonic signal showing a discontinuity (crack) at about 7.8m, caused by lateral soil movements.

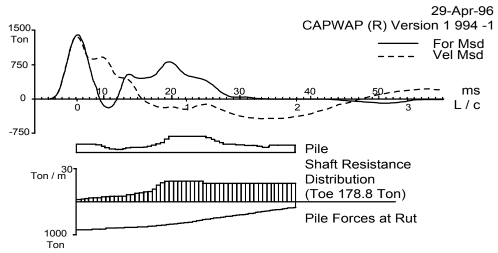

Fig. 13 High strain dynamic load test signal showing a crack in the pile at about 8.0m.

An inadequate retaining system for excavation work has caused the lateral movement to the pile top about 80cm and a crack has developed in this pile. The crack was also detected by the high strain dynamic load test performed to determine the pile capacity of the cracked pile (see Fig. 13).

From Fig. 12 and Fig. 13 the duration of pulse in the sonic integrity test signal is about half of that in dynamic test signal. The short duration (high frequency) pulses can resolve reflections from narrow impedance changes. In such case presence of a crack in the pile is more clearly indicated by sonic integrity test signal (low strain) than the dynamic test signal (high strain).

An assessment of pile defects based on the sonic integrity test records on 8,689 bored piles in Bangkok subsoil and their construction records including soil conditions was carried out. The assessment indicates that integrity of 285 piles (3.3%) out of 8689 piles has been suspected. They are summarized in the table below;

Type of Defect	Causes	%
Poor concrete at pile top (0-3m)	cutoff level near the ground or not enough overcast	0.1
Cracks/ discontinuities	Excavation works for pile trimming and Construction activities	2.2
Size reduction	Inadequate casing length or soft clay layer variation in thickness	1.0

From the above assessment, most of the defects are found to be in small piles with a diameter of 0.60m or smaller. Study of piling and excavation plans show that piles with a crack indicated by the sonic integrity were located in the vicinity of excavation boundaries.

A total of 1491 piles were found with localize increments in pile size. All of size variations including size reductions are found to be at the transition interface of temporary casing and soil layer, where soil strata changes also occur.

CONCLUSION

Sonic integrity test is an effective method to assess the pile integrity. Computerized acoustic technique developed by TNO, PDI and IFCO is commonly used in Bangkok for both driven piles and bored piles. About 3.3% of 8689 piles have been interpreted for either size reduction or poor quality of concreting or cracks/discontinuities.

Toe reflections are generally clear for small piles with slenderness ratio of 40. But only in few cases, especially toe grouted, toe reflection has been observed for longer piles with toe embedded below 30-35m.

Signal interpretations have been compared with soil investigation results and construction records. Causes for defects could be identified and conformed to casting records.

Minor defects, such as small cracks can be predicted in many instances and nature of them need to be verified by further visual inspection.

The predicted defects and possible causes verified from the construction records would help the piling and excavation contractors to be aware of the causes of defects associated with construction practice.

ACKNOWLEDGEMENT

The authors express their appreciation to E.D.E. Co. Ltd. in supplying test records and to Mr. Sujit Onsri and Mrs. Piyamitr Sura-auggool for their assistance in the preparation of this paper.

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