PILE DIAGNOSTICS BY LOW STRAIN INTEGRITY TESTING

Ravikiran Vaidya
Managing Director
Geo Dynamics
Baroda

D.L. Shah
Professor
M.S. University of Baroda
Baroda

Synopsis: Today Pile Foundations are installed ranging from 450mm to 2m diameter and designed to carry very heavy loads for flyovers, bridges, multi-storied buildings, jetties etc. Their use has also increased due to increased infrastructure development recently, thus requiring a quality control tool that quickly evaluates shaft integrity without affecting construction schedule. The paper describes **Low Strain Pile Integrity Test Method standardized as per ASTM D5882.** It includes theory, **case studies** and the benefits of using this method on construction sites. The results of such studies have also been confirmed with further investigations to prove the reliability of testing.

INTRODUCTION

The increase in thrust to infrastructure provided by successive governments has resulted in increased construction of flyovers, bridges, jetties, ports, multistoried buildings etc. Many of them are located in areas that have weak underlying strata and use of pile foundation to transfer superstructure loads is quite common. Today piles are being cast from 450mm to 2m diameter with loads ranging from 100 tons to 2000 tons and with depths upto 50 to 60m. Hence a requirement to quickly evaluate the quality of these shafts in terms of cross-sectional changes, cold joints, socketing, concrete quality has greatly increased. Thus it is imperative to have some quality control tool to quickly evaluate the structural integrity of these shafts, since not only they carry heavy loads, but are also hugely expensive. The commonly employed methods of coring, drilling, television survey, vibration testing and load tests for detecting defects and irregularities in piles have, only resulted in varying degree of success. In comparison, low strain pile test is a quick, inexpensive and fairly reliable method, which is the primary reason why it has been accepted in various parts of the world. The test is referred to as the Low Strain Method because a small hammer is used to generate a short wave of appreciable acceleration but low strain levels. The test has been standardized as per **ASTM D5882** and is also a part of the Draft Indian specifications IS:2911. It is also part of various code provisions worldwide, e.g., U.K. Canada, Netherlands, Germany, S.E. Asia, China, etc. The low strain method can be used to test a large number or all piles at a construction site. The result for each pile tested is an acceleration or velocity curve plotted as a function of time. This curve is investigated for any wave reflections, which indicate a change in pile properties.

STRESS WAVE PROPAGATION IN A PILE

The linear, one-dimensional wave equation represents a pile that is long compared to its width or diameter and which consists of linearly elastic material. A violation of this basic condition may imply an L/d ratio less than 10 or poor concrete quality inside the pile. Figure 1 shows a pile length versus time plot, which is often used to explain the echo effect of a stress wave reflection. As a compressive downward traveling wave encounters a cross sectional reduction, an upward traveling tensile wave is generated which can be observed at the pile top at a time that equal to twice the distance of disturbance from the pile top divided by the wave speed, c. Thus a waveform traveling through the pile will reflect due to three reasons: changes in cross-section, changes in soil properties and changes in material property of the pile. Thus reflections are primarily due to change in impedance Z or soil strata changes. This pile impedance, Z, is the product of cross sectional area A. and elastic modulus, E, divided by the wave speed, c. a decrease in either A or E can result in a tensile reflection while an increase of either A or E will produce a compressive reflection.

Figure 2 is a measured pile top velocity record obtained from a low strain test. The record demonstrates a pile with no cross sectional changes with a clearly indicated toe signal at time 2L/c (L is the total pile length). In the absence of energy losses due to friction, end bearing or internal pile damping, the toe signal would be twice the amplitude of the impact signal.

METHOD OF TESTING

Figure 3 shows the schematic of the P.I.T. instrumentation using a P.I.T. collector. Other hardware components include a hand held

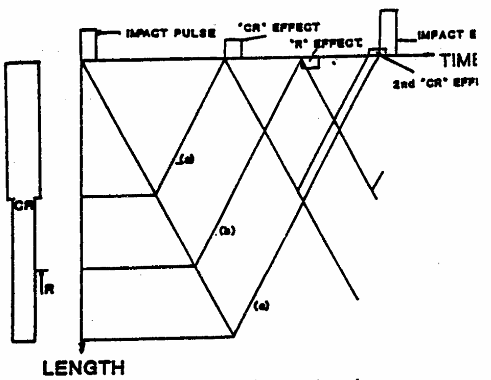

Fig. 1 Pile length versus time plot.

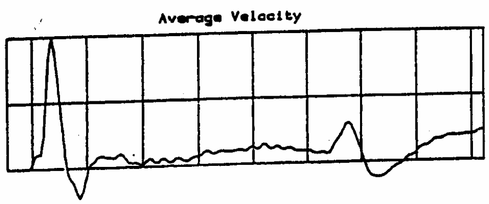

Fig. 2 Typical P I T record.

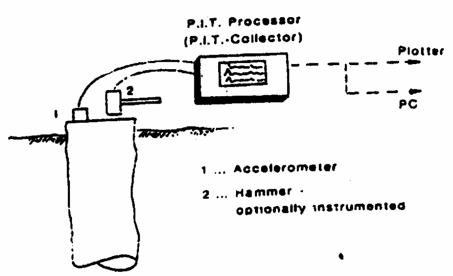

Fig. 3 Schematic of Pile Integrity Testing.

hammer with an integral plastic cushion and an accelerometer. The P.I.T. processor provides signal conditioning, digital signal processing, digital signal storage and for output, an LCD screen.

The first and sometimes most important step for any low strain test is the preparation of the pile top surface. In fact, depending on the construction method, it may be necessary to remove several inches or feet of the upper concrete if it has been contaminated with soil, bentonite slurry or other foreign materials during construction. After a clean, healthy and hard concrete top surface has been exposed, the accelerometer is attached to the pile top surface with a thin layer of soft paste like vaseline, petro-wax etc.

After this preparation, an impact with the hand held hammer is applied. The impact typically generates accelerations in the 10 to 100 g range, pile strains around 10^{-5}, velocities near 30 mm/s, and displacements less than 0.03 mm. Accelerations produced by several hammer blows are integrated and displayed as velocities on the processor's screen. Consistent records are selected, averaged, scaled and then redisplayed. Averaging reinforces the repetitive information from pile or soil effects while reducing random noise effect.

WAVE SPEED AND PILE LENGTH CALCULATIONS

The low strain test method has two unknowns, the length and the wave speed & one of them has to be known in advance. The test engineer to determine the length or wave speed uses the following two procedures.

- ✓ Assuming that the pile or shaft length is known accurately, the wave speed is back calculated from the time between impact and pile toe reflection.
- ✓ If the shaft length is not known then a wave speed is assumed based on experience of that site, and the pile length is then calculated from the time of toe reflection. Since wave speeds of piles in the same site normally fluctuate within $\pm$ 5%-10%, similar variation in predicted length must be expected.

EXAMPLES

The following few examples explain the benefits obtained using PIT on construction projects, where either problems were suspected or to ascertain the quality of shafts before proceeding with superstructure work.

1. **Determination of pile length:** Pile integrity tests were performed on 40 piles to determine their length. The tests were performed for multistoried residential building at Mumbai, since there were no previous records available. The results of such testing indicated most of the piles to be in the range of 10-11m; e.g. refer to Figure 4. The record estimated the pile length as 11.0m. Actual coring in the pile concrete carried out on one pile to confirm the PIT results showed the pile length as 10.5m. The drilling was carried out using 100 mm / NX size rotary drilling rig. The graphical log is shown in Figure 5 Thus, it confirms the results obtained by Pile Integrity Test within a range of 5%.

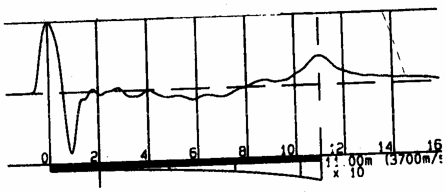

Fig. 4 P I T data to evaluate pile length.

Bore Hole Size : 100mm/Nx | Ground R.L.: — | Date of Commence : 27 - 05 - 2001
Method : Rotary | Ground Water Depth : Not Met With | Date of Completion : 30 - 05 - 2001

Depth (m)	Bore Hole Dia (mm)	Thk Of Layer (m)	Stratum Description	Samples Depth	Samples Type	Blows/15cm 15	30	45	60	SPT N	CR / RQD %	Other Tests / Remarks
1			Pile Concrete	1.00	RUN1						97/97	
2				2.20	RUN2						88/88	
3				3.55	RUN3						97/70	
4				4.80	RUN4						97/74	
5	NX			5.90	RUN5						80/83	
6				6.65	RUN6						88/88	
7												
8				8.25	RUN7						83/88	
9				9.10	RUN8						86/28	
10		10.50		10.00	RUN9						40/17	
				10.50	RUN10						44/20	
11												
12			Highly Weathered Reddish Brown Volcanic Breccia Rock	12.00	RUN11						07/nil	
13	NX			13.00	RUN12						15/ nil	

Fig. 5 Coring data.

2. **Integrity of offshore pile:** One of the important applications of P.I. T. is to check pile integrity for offshore piles where conventional testing is difficult and very time consuming. Figure 6 shows PIT data as collected from one of the jetty construction near Mumbai. The record indicates a small kink around 10m implying start of soil or seabed level at that level. Loose soil from 10m to 14m seems evident that does not contribute much to side friction. Change in strata that is most probably hard rock seems present from 14m to pile toe. Socket length is approx. 2m into hard strata. These findings were also confirmed from soil bore log available at site. The wave speed noted for this pile was 4200m/sec, indicating uniform concrete quality.

3. **Integrity Of Long Offshore Pile:** Figure 7 shows one such typical data of bridge near Cochin. Data indicates 6m depth of water. Loose deposit available from 15m to 35m, thereafter-medium stiff clay is evident. The record indicates fairly uniform shaft with increase in soil resistance from 46m

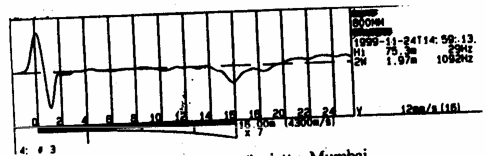

Fig. 6 PIT data for jetty, Mumbai.

to pile toe. Thus even a long pile with an L/d ratio of 47 can be tested using P.I.T.

4. **Identifying defective pile:** Pile having defects like cracks or joints can be very easily identified by this method. Figure 8 shows such record for a project in Goa. More than 100 piles were tested to ascertain pile integrity, since it was suspected that some piles might have defects. The data indicates uniform shaft upto 2m. Defect seems evident around 4m. Similar reflections are evident at 4x/c time (9m) and (6x/c) 14m. This indicates that the pile has serious integrity problems that need further investigation. Excavation of this pile confirmed defect around 4m, thus justifying the use of Pile Integrity Testing.

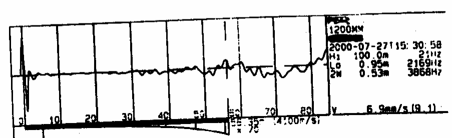

Fig.7 P I T data for long offshore pile, Cochin.

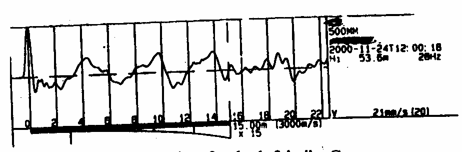

Fig. 8 P I T data for doubtful pile, Goa.

The following describes case study for a Hotel Project in Mumbai. Construction records did not indicate any integrity problems in the pile. The pile was randomly selected for testing as some other pile in the area was suspected to have poor integrity. Refer to Figure 9, the tested pile surprisingly shows loss of integrity around 4.5m from test level that was difficult for the client to accept. Coring was hence conducted to confirm integrity test results. Core test results confirmed defect in the pile approximately at the same level.

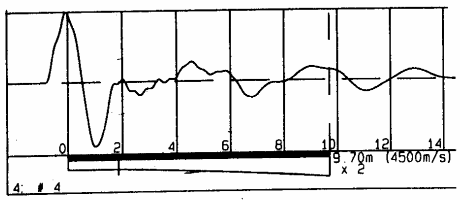

Fig. 9 P I T data for doubtful pile, Mumbai.

BENEFITS OF PILE INTEGRITY TESTING

1. The test is simple, reliable and can be quickly performed. The test determines defects in pile and with additional field information, it is possible to ascertain the nature of defect, viz. reduction in cross-section, cold joint, poor concrete quality etc.
2. It can be used to identify piles for further static or dynamic testing instead of random selection thus ensuring better quality control.
3. The test can be used to ascertain pile length with reasonable accuracy.
4. It can also be used as a quality control tool for both offshore and onshore structures.
5. Cost of test is usually fraction of the entire cost of piling. Thus clients, contractors or consultants can use it on large or all nos. of piles at their project sites to quickly evaluate shaft integrity.

LIMITATIONS

1. The test cannot be used to ascertain load carrying capacity and is not intended to replace static or dynamic testing.
2. The method is not applicable for segmented pre-cast r.c. piles or steel piles.
3. Piles with multiple defects or highly varying cross-section are difficult to analyze using this method.
4. The test can be used for an L/d ratio of around 45 to 50 although the skin friction along the pile also governs it.

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