DISCUSSION OF INFLUENCE ON PILE QUALITY BY REMOVING PILE FOUNDATION CASING WITH VIBRATOR

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Abstract: The process of pile sleeve removal will affect the quality of piles directly. In general, there are three types of working method to remove pile casing and the equipment also has significant effect on the quality of pile after casing removal. Recent years, Non-destructive Testing methods were used to assess the quality of pile. The main purpose of this paper is to investigate the effect of casing removal on the quality of constructed bored pile by vibrator. The result indicates that the quality of constructed bored pile is able to meet the requirement of design specification or the casing is removed by vibrator.

Keywords: pile, ultrasound, Non-destructive Testing method

1. PREFACE

Due to active development of the domestic economy in recent years, large structures of civil construction engineering have increased progressively; relatively, pile foundations are used extensively, so various buildings with considerably large loads can sit on the well bearing layer. For locations with soft ground in particular, the use of large and long pile foundations is very common. The success of pile foundation work is influenced by the technique and quality of pile foundation work to a great extent. Bad workmanship may easily cause defects in the pile itself and during construction the continuity and thoroughness over the entire pile foundation can be influenced very easily by improper speed of operating tremie pipe or other human and machine equipment factors during quick sand or pouring of concrete (i.e. Bored Piles). This may cause possible defects in the pile and these defects can possibly be honeycomb, crack, necking, insufficient protecting layer for reinforcement, miscellaneous objects contained in concrete, as well as loss of cement and aggregate in concrete, which influence the normal function of pile foundation to a large extent. In order to ensure workmanship of pile foundation, there is an underground water level for common ground and casing excavation is used to prevent collapse of wall holes. In order to ensure the quality of pile foundation, non-destructive testing is often used to inspect the thoroughness of pile foundation without breaking it.

2. CONSTRUCTION METHOD FOR CASTING PILE FOUNDATION

The casing excavation for general pile foundations is divided into semi casing excavation and full casing excavation. For semi casing excavation, the casing only reaches the bottom of the pervious bed and no casing is applied on the non-pervious bed below. The so-called full casing excavation is that the full altitude of pile hole uses casing to protect the wall hole. This technique is mostly adopted for pervious bed within the pile hole (i.e. the easy collapse bed) when it reaches above 2/3 of full altitude. In Taiwan, this technique is often used to excavate for pile foundation due to the property of stratum structure. The general principle of determining the depth for the casing is shown as Figure 1, and then internal diameter of casing needs to be approximately 20 cm larger than the diameter of piles with thickness of 9mm to 12mm.

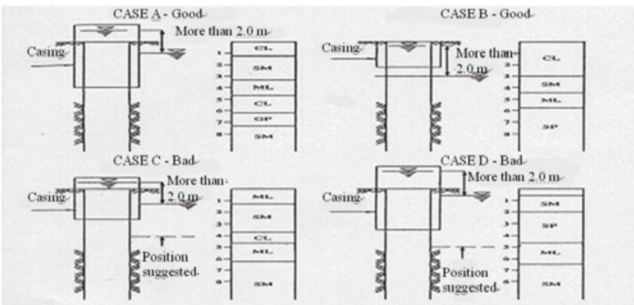

Figure 1. Illustration of good and bad installation position for protecting casings

The procedures of excavation for general full casing bored piling are shown in Figure 2; items are added to work procedures according to work machinery.

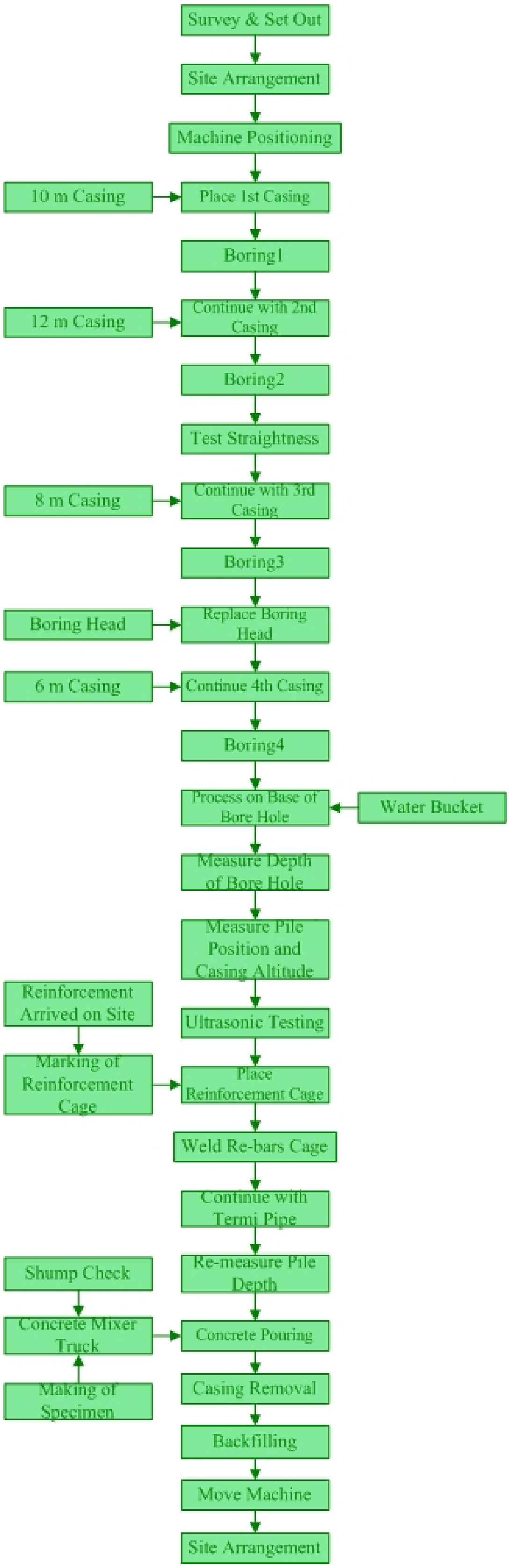

Figure 2.Flow chart for casing pile foundation work [7]

There are few ways for removing the casings, but all of them consume lots of time. The first method maintains vibration with a vibrator and removes the casing with a crane. This method is mostly used for semi-casing or casing with length shorter than 30 m; it is faster in terms of time but excessive vibration may cause separation of aggregate. The second method uses casing oscillator, which lifts the casing upwards by oscillating to the left and right at an angle of 23 degrees for reduction of friction. The third method uses fully swiveling rotator, which lifts the casing upwards by rotating the casing in the same direction at 360 degrees. These methods need to see the size of the working environment and soil characteristics for consideration of machine application and time reduction of casing removal.

Since the process of making piles on site directly influences the quality of concrete, the removal of casing is also one of the key points influencing the quality. This article tries to discuss the workmanship of removing casing with vibrating technique and take the testing data including core test and ultrasonic wave test on a certain site in Taoyuan for discussion.

3. LITERATURE REVIEW

3.1 Non-Destructive Testing

The method of inspection on pile thoroughness developed over recent years can be summarized into two categories. The first category contains direct inspections such as “Excavation”, “Air Drilling”, “Coring”, “Visual Borehole Inspection by Closed Circuit Television” and “Caliper Logging”; second category contains indirect inspections (also referred as non-destructive inspection) such as “Acoustic”, “Gamma Ray Scattering”, “Vibration”, “Shock”, “Seismic”, “Dynamic Pile Test”, “Integral Compression Test” and “Electrical Test”.

3.2 Acoustic

This technique is developed by French CEBTP at the end of the 1960’s, which uses principle of acoustic wave having different transmitting speed in different medium to inspect pile thoroughness. Since the methods of testing are different, they can be basically divided into two categories:

(1) Single Hole Inspection

The “Single Hole Inspection” is shown as Figure 3 and it uses a transmitter to send seismic waves from the pulse generator; the seismic wave generated by transmitter that combined with receiver on a detector is accepted by the receiver via transmission along concrete medium. When the pulse generator produces pulse, the arrival time and amplitude of signal received by the receiver of oscilloscope are activated at the same time. The pile defect is then tested with delay of vibrating signal received or characteristics of signal loss; the signal received will be processed and analyzed by an experienced engineer to obtain acoustic speed near the wall holes for pile drilling. Concrete with excellent quality will have higher and stable acoustic velocity (approximately 4000m/s); on the other hand, the acoustic velocity will be lower and more disordered. The advantage for this technique is that it applies to each different type of pile waves and is not limited to pile length; the test can be commenced after 2 to 4 days of concrete pouring. The disadvantage is that observation pipe must be installed in advance when there is no pre-drilled hole for the pile, and this increases material and installation cost; in addition, the scope coverable by the test relates to energy of transmitter and distance between transmitter and receiver, thus the single hole acoustic shall be made when the pile diameter is smaller or there is already pre-drilled hole to use.

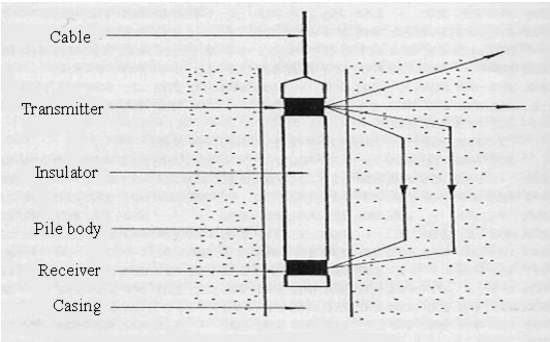

Figure 3. Single hole acoustic inspector

(2) Double Hole Inspection

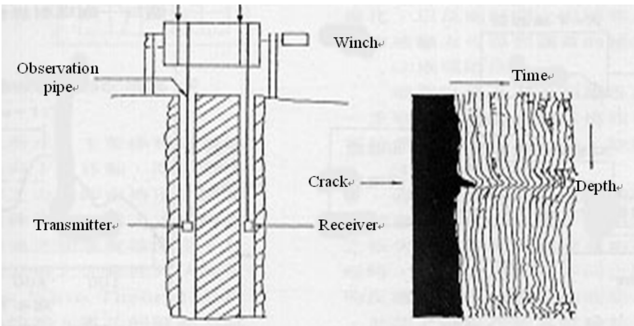

Figure 4. Double hole acoustic inspector

In double hole inspection, a transmitter is placed in one hole and a receiver is placed in another hole to test the sectional thoroughness between two holes (as per Figure 4); the principle of wave transmission and receipt is the same with single hole technique. The advantage is that double hole inspection covers the scope that single hole inspection cannot cover; the disadvantage still lies on the additional cost on material and installation of observation pipe. Furthermore, the defects on concrete (e.g. protecting layer for reinforcement) out of acoustic route between two holes cannot be inspected; for piles with larger diameter, the inspection scope can cover most of the pile body if more than two observation pipes are installed. Generally speaking, three observation pipes shall be installed for pile diameter at 0.6 to 1 m and four observation pipes shall be installed for pile diameter greater than 1 m.

3.3 Others

Chinshiu Chang, Wenli Wang and Wen Huang (1987) pointed out that there are many factors for defective quality on bored piles. Since the piles are buried underground, defects cannot be checked easily after completion and some defects do not show the impacts within a short period; there is still potential hazard causing work failure once the pile confronts external force or underground water. According to records of present literature already published, many pile foundation work often induces bad thoroughness of pile or insufficient load bearing capacity due to work method or geological conditions, which impacts the safety of structural object above. In his investigation, Lambert (1973) discovered that ratio piles discovered as danger and must be repaired was approximately 7 % to total pile quantity. Davis and Dunn (1974) discovered piles that had problems were approximately 19% and approximately 8% of the piles needed to be repaired; in another case, they discovered piles that had problems were approximately 16 % and approximately 6 % of the piles needed to be repaired. Fleming (1985) discovered piles that had problems were approximately 2 %. The inspection on pile thoroughness was developed from demands, which performs inspection on completed piles for thoroughness of pile body and improves workmanship of pile foundation construction. Among each non-destructive inspection, Shenghuo Ni (1995) pointed out in his article that advantage of acoustic was the possible achievement on inspection diagram of depth section over the whole pile, which is applicable for different types of pile foundations. However, the disadvantage was the need for preserved holes that increases additional cost and construction burden; furthermore, the defects on concrete (e.g. protecting layer for reinforcement) out of acoustic route between two holes cannot be inspected. In their practical research on non-destructive inspection for pile foundations, Mingde Liang and Jenshin Jhong (1988) used pile foundation for Chongyang Bridge to point out that result from vibrating test in non-destructive inspection showed normal thoroughness and load bearing capacity on all pile foundations, and the stiffness obtained from vibrating test and static load test complied with design requirement.

4. METHODOLOGY

In order to properly achieve the quality of pile work, this test uses ultrasonic wave, concrete coring and compression test to evaluate and inspect if the vibrating casing removal can achieve work standard against concrete quality and casing grouting.

(I) Ultrasonic wave

a. Purpose of ultrasonic wave

(1) To see if concrete contains soil, bentonite and impurities.
(2) To see if concrete contains honeycombs.
(3) Status of change in concrete quality.
(4) Large crack or cavity.
(5) Depth of pouring.
(6) Material separation.
(7) Weak concrete.

b. Basic principle of ultrasonic wave

For homogeneous concrete without defects for differences, the acoustic transmitting velocity is a fixed value of approximately 4000m/s; if the concrete contains soil, ashes or honeycombs, the acoustic transmitting velocity will reduce. Concrete with different quality has different time of acoustic transmission according to this; special instrument is then used to measure time and velocity of transmission between two detectors on concrete within the walls to test the concrete quality and defects.

$V=f(E, \delta, S)$

E：Dynamic elastic modulus of material

δ ： Density of material

S：Shape

When the concrete contains a foreign substance with mean density different to the concrete, ultrasonic wave equipment can be used to find out defects on concrete piles or diaphragm walls according to different transmission of wave speed.

The entire system of ultrasonic wave equipment for testing of thoroughness is illustrated as Figure 5. An electrical quartz is set within the transmitter and the tension wave is triggered via oscillator of main machine to produce a micro shock wave from the quartz to concrete, the receiver on the other side will then immediately receive first set of wave and record accordingly.

The micro shock wave is produced in two types during test, i.e. longitudinal wave and horizontal wave, which are the so-called P wave and S wave. Since the velocity of longitudinal wave is far greater than horizontal wave, the first wave that passes receiver is the longitudinal wave. The shear wave is reflected back by the PVC pipe wall and transmission time from transmitter to receiver can be plotted from oscillograph. Since the cable connecting transmitter (or receiver) is pulled up slowly along the pulley attached with encoder, the depth of entire wall body and transmission time can be completely plotted and recorded at the same time.

In order to keep all data tested on site away from influence of noise and electrical noise, oscilloscope is used to check signal quality of each transmitting wave and prevent incorrect judgment of concrete thoroughness.

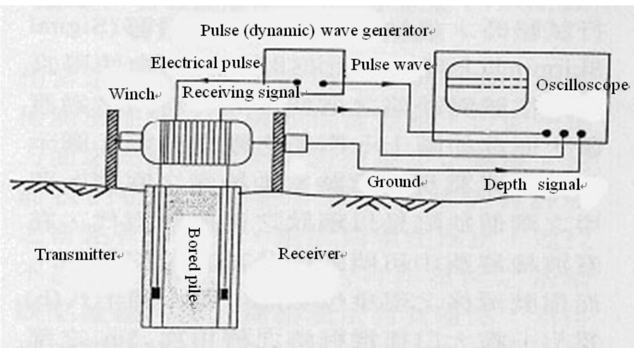

Figure 5. Illustration of double hole acoustic inspection system

Ultrasonic inspection and instrument

The instrument needed for this test mainly includes the following items:

(1) Ultrasonic tester with digital display for transmitting time of ultrasonic wave;
(2) Transmitter-47KHZ that transmits ultrasonic wave;
(3) Receiver-47KHZ that receives ultrasonic wave;
(4) Winch: capable of controlling height of detector within inspection pipe;
(5) Ultrasonic tester that checks quality of signal received;
(6) Polaroid camera that continuously record result of measurement;
(7) 100 m cable: specially covered water-proof cable;
(8) Pulley guiding facility: the test methods that guide cable and send signal of depth to the main machine are mainly divided into four major steps of ultrasonic inspection:
    (a) Perform amplifier gain adjustment prior first measurement at each base and use ultrasonic testing system to control the quality of measurement.
    (b) During the test, place the transmitter and receiver into testing pipe separately.
    (c) Adjust the height of transmitter and receiver, so they are on the same plane.

Rotate the winch, place both the transmitter and receiver to the base of testing pipe, and then slowly pull up transmitter from base of testing pipe, where the receiver in other testing pipe will receive ultrasonic wave of non-destructive inspection. The inspection process is shown as Figure 6.

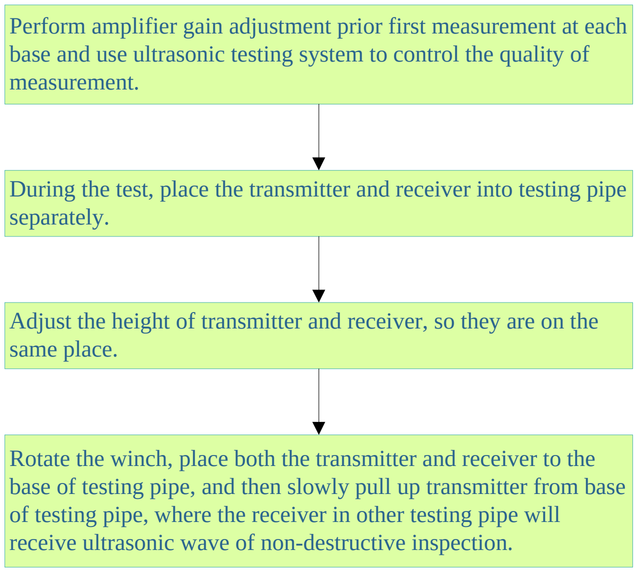

Figure 6. Flow chart of ultrasonic inspection

(II) Compressive strength of concrete core sample

A. Purpose of compressive strength in concrete core:

Coring machine is used to obtain the circular column specimen for testing quality of structural concrete.

B. Description:

(1) The core test is often used to test quality of structural concrete that is different from quality of compressive specimen for general concrete. In addition to material quality and quality of freshly mixed concrete that influences quality of structural concrete, the status of workmanship seriously influences the structural concrete.

(2) During coring of specimen, drilling on reinforcement must be prevented; the selected part shall consider dynamics that still have no safety concern.

(3) After completion of cutting, the coring specimen obtained often has different length to traditional specimen; calibration must be made at this time and the standard is shown as (Table 1).

(4) ACI and CSA specify that if the compressive specimen has $\sigma'c$ less than 35 kg/cm^2, at least 3 specimen must be obtained and average value of these three specimen must at least equal to 0.85 $\sigma'c$; moreover, none of them shall be less than 0.75 $\sigma'c$, otherwise the quality is not appropriate and further steps shall be taken to inspect the structural concrete.

(5) The core specimen is not the most reliable index for concrete quality, thus it often needs to be accompanied by non-destructive inspections such as rebound hardness or anti acoustic.

Compressive strength = $f\frac{P}{A} = \frac{4fp}{\pi D^2}$ (kg/cm^2)

f: correction factor for length: width ratio, which is acquired according to interpolation in Table 1.

p: maximum load (kg)

A: sectional area of specimen (cm^2)

D: mean diameter of specimen (cm)

Table 1. Correcting coefficient for length of specimen

Length / Diameter	2.00	1.75	1.50	1.25	1.00
Correcting factor on strength	1.00	0.98	0.96	0.93	0.85

C. Instrument and test procedures:

The instruments include:

(1) Core drilling equipment.
(2) Saw.
(3) R-Meter.
(4) Compression tester.
(5) Specimen covering equipment.

Test procedures:

(1) Use R-meter to find the location of reinforcement near point to be drilled first.

(2) Use the coring machine to take specimen with length / diameter ratio at approximately 2 from spot away from reinforcement; the diameter of specimen must be 3 times of maximum aggregate.

(3) Cut the cored specimen flat with a cutter and make the dimension at approximately $1/d \cong 2$, grind with a grinder, then put it into saturated lime water for at least 40 hours and keep the temperature at range of 23 ± 1.7℃.

(4) Take out the core specimen before test, then measure the diameter and length after capping.

(5) Place the specimen under compression tester and execute the compression at load of standard velocity at 1.4~3.4 kg/cm^2 (20~50psi) per second.

(6) Record the maximum loading.

D. The following few items are key issues that worth discussion when executing test of compressive strength on the core:

(1) Size effect: length ratio, diameter
(2) Status of water content
(3) Reinforcement contained
(4) Direction and position of core
(5) Age
(6) Work condition

E. Test result of ultrasonic and concrete coring

Both the ultrasonic and concrete coring tests comply with design standard; the piles have been tested by ultrasonic wave and the result from the acoustic inspection diagram shows that the concrete has no bad pile base, crack, weak concrete and aggregate separation. Moreover, the strength of concrete at each depth from core test complies with the designed 280kgf/cm2. For top of piles with bad quality, minimum strength of specimen achieves approximately 93 %; this part of bad concrete needs to be knocked off during design and the soil collapsed during boring floats to the top of casing along with concrete pouring, so the height of general concrete pouring is 90~100 cm higher than the designed height for knocking off excessive bad concrete in the future. In addition, the judgment of ultrasonic inspection is shown in Figure 7.

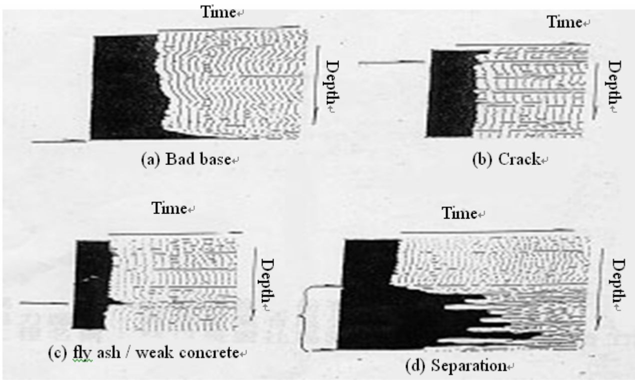

Figure 7. Defect illustration for analysis on complete test result with ultrasonic wave

The test result is that complete test of ultrasonic wave complies with the standard and example is only taken with Figure 8 that shows photo of ultrasonic result. The core test expresses relationship between concrete strength and depth in Figure 9 and the test values are both greater than the specified values.

Figure 8. Photo of ultrasonic wave

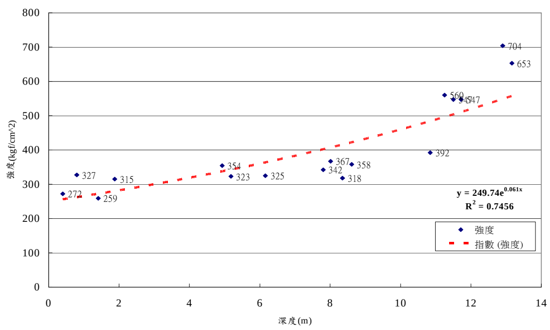

Figure 9. Relationship between concrete strength and depth

5. CONCLUSION

This case combines the result of core test into design strength and the appearance of core specimen shows no obvious separation of aggregate. According to the relationship between strength and depth of specimen for the core test, the deeper the depth of piles is obtained, the stronger the strength is. The minimum strength for top of pile is 259 kgf/cm2 and maximum strength of pile base can reach 700 kgf/cm2. The bad concrete on top comes collapsed or base soil mixing with water, which forms mud and rises along with concrete due to floating ability and this is the part of the concrete designed to be knocked off. For greater strength at base, the reason can possibly come from the work process; the casing is removed with vibrator and causes vibration in casing, which sinks and compacts the aggregate, so that the concrete strength tends to increase from upper layer to lower layer. In addition, there is 30 % of strength between strength of core and specimen (1.5 M of the pile); besides the reason for bad concrete, the casing vibration can also be one of the reasons.

The test result from ultrasonic wave was good, and the judgment showed no bad pile base, crack, weak concrete and aggregate separation.

The quality of pile mainly needs to strictly request each step during the work process to achieve quality assurance; from the process of this pile work, we know that if tremi pipe has not been dismantled in sections, it is easy to cause floating of steel reinforcement. In order to prevent floating of reinforcement cage, several "#" shapes can be welded inside of the reinforcement cage to prevent floating of reinforcement cage. In addition, excessive vibration of casing work would cause aggregate separation and vibration of base can easily cause soil slide; thus temporary measures of disaster prevention need to be done well.

The application of non-destructive inspection on piles is already very popular in advanced countries and it has great effect for enhancing the quality of piles. Therefore, correct work procedures must be strictly required for work process to ensure pile quality and provide important reference data to site works; the result of analysis will be made as an important reference index for pile works. In order to progressively improve the quality of domestic pile work, the cost of non-destructive inspection shall be included in the budget of actual work. This can ensure quality on one hand and prevent irreversible consequences on the other hand. Therefore, the non-destructive inspection on piles is worthwhile to be promoted for application.

6. REFERENCE

[1] Chinshiu Chang, Wenli Wang and Wen Huang (1987), Thoroughness Inspection on Bored Piles, Geotechnical Engineering Journal No. 18.

[2] Mingde Liang and Jenshin Jhong (1988), Case Study on Chongyang Bridge for Non-Destructive Inspection on Piles, Geotechnical Engineering Journal No. 24.

[3] Shenghuo Ni (1995), Non-Destructive Inspection on Piles and Cases, Geotechnical Engineering Journal No. 52.

[4] Shieji Wang (1999), Practical Civil Engineering Construction, National Institute for Compilation and Translation.

[5] Chapter 1 of Work Manual, Residential and Urban Development Bureau, Provincial Government of Taiwan.

[6] Jhaolong Huang (2005), Quality Control and Testing on Concrete Material, pp.222~224, Jhan's Bookstore, Taipei.

[7] Highway Construction in Taiwan, Book 30, Volume 9, March 2004, pp2-19.

[8] A.J.WELTMAN (1977) "Integrity Testing of Piles: A Review," DOE and CIRIA Piling Development Group Report PG4, September.

[9] Davis. A.G. and DUNN.C.S. (1974)"From Theory to Field Experience with the Non-Destructive Vibration Testing of Piles", Proc. Insfn. Civil Engrs, Part 2,Vol. 57. Dec. pp.571~593.

[10] E. P. BRUCKL. (1984) "Pile Integrity Test," In-terfelsPresentation-Athen, November.