Rectification of Low Consistency Bored Cast In-Situ Piles by Grouting- Some Case Studies

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1. Introduction

Construction of mega structures are increasing with the recent development of the country. Many structures need deep foundations such as piles, in order to transmit foundation loads through soil strata of low bearing capacity to sufficiently strong soil strata or rock strata having high bearing capacity. The methods of construction and depth of piles vary depend on the geology of the site. Piles derive their carrying capacity from a combination of friction along their sides and end bearing at the pile point or base. There are many types of piles developed and used extensively in the construction industry and one of the most common piles used in Sri Lanka is bored cast in situ piles which can be installed down to greater depth with large diameter. Sometimes, such bored cast in situ concrete piles fail to reach the designed load due to several reasons. In such a situation it is necessary to go for another two piles with same specification and the cost of additional piles should be borne by the contractor. Therefore, of such a low consistency pile to meet the designed load is massive economic benefit.

2. The Piles

The main function of bearing piles is to transfer the load to lower levels of the ground which are capable of sustaining the load with an adequate factor of safety (British Standards Institution 1986). Therefore, it is essential to carry out geotechnical investigation and study the available data before foundation design to identify the variability of strata under-laid by proposed structure. The most suitable method of construction of foundation is determined by studying maps and records relating to geology, geomorphology, groundwater level, drainage systems, flooding, landslide, land subsidence as well as cost of construction. When no adequate bearing stratum exist at shallow depth, it is necessary to design deep foundation including piles.

2.1. Bored Cast in Situ Pile

Bored cast in situ piles are constructed by rotary boring, or percussive methods of boring, and subsequently installing reinforcement cage followed by filling the hole with concrete (Yung, Keung-Shing, 2001). During the boring, steel casing is sunk into the ground in case of collapsing of soil strata occur and usually 6m length of casings jointed to reach the required length (Figure 1). Boring tools such as soil auger, rock auger, boring bucket and core barrel are used depending on the strata.
2.2. Testing Methods for Pile Consistency

There are two kind of tests mainly used to check the consistency of the pile.

- The sonic integrity test is a non-destructive crosshole seismic test for quickly and economically checking the integrity or continuity of an installed pile foundations using pre-installed pipes. The method is referred to as a low strain test and is routinely used for quality control purposes in piling projects. The test will detect pile defects like cracks, voids and soil inclusions, changes in the pile diameter, and major variations in the consistency of the pile material. The method does not provide any information on the load bearing capacity of the pile.

- Pile driving analyzer (PDA) monitors the pile for damage by checking the recorded traces for the presence of any velocity wave return, prior to the arrival of return wave from the pile toe. Since, there is no apparent significant reflection is noted the pile may be considered to have good integrity at the time of testing. Case pile wave analysis program (CAPWAP) is based on a mathematical model simulation and results reported by attaining best matched model (Alvarez C., et al, 2006). Using PDA and subsequent CAPWAP analysis it is possible to estimate the maximum compressive and tension stresses, mobilized capacity, unit skin friction, etc.

In addition, the quality of concrete was observed using the results of cube crushing strength tests.

3. Rectification & Consolidation

It is necessary to carry out more reliable and economical test like sonic integrity test after finishing the concrete works of the pile to check the consistency. If the test detects any defects which are not in acceptable range, those defects should be rectified and consolidated.

3.1. Pile Coring

Defects were explored by coring the pile. Number of holes and the locations of the holes were decided by interpreting of the sonic test results using Tomosonic software in each section (Figure 2). Rotary wash boring technique is the most suitable technique for coring the pile and it was continued until 100 core recovery and 80 % RQD and or end of the pile bottom. The alignment of the machine was not changed until completion of the hole and level was continually checked at each and every pullout to ensure that hole is vertical. It is necessary to install steel pipe with grout nipples on top of the hole and should be well sealed using chemical.

Figure 1 - Pile Coring

Figure 2 - Bored Cast In-Situ Piling
3.2. Pile Grouting
It was possible to have an idea about the defects of the pile after inspecting the core samples. Before starting the grouting process, all the holes were cleaned by compressed air and water. It was continued until clear water came out from the hole. Grout volume could be estimated by measuring the pumping water to the core hole and it had helped to arrange the material for grouting. Ordinary Portland cement and water were properly mixed using colloidal mixer with the ratio of 1:0.4 by weight respectively and filtered to confirm no flocks in the mixture. Admixtures were used to reduce viscosity and increase the strength of the grout mixture and tested for the viscosity and strength by marsh funnel test and test cube crushing test. Grout pressure, grout intake and time consumed were noticed for each hole. When two holes were interconnected, grout was injected from one hole and continued until same concentration grout came out from other hole. Then the other hole was plugged and maintained the pressure at least for 15min. When there was no interconnection between the two holes, each hole was grouted separately by using pipe inserting in to the bottom of the hole and subsequently removing the pipe with filling of the hole. Grout pressure was maintained at least 10 minutes after the hole was filled with grout.

4. Case Study
Geo Engineering Consultants (Pvt) Ltd (GEC) have successfully rectified many low consistency piles during the last three years.

4.1. Case Study No. 01 - Outer Circular Highway Project
It was essential to construct piles for viaduct area in outer circular highway project and several of them were detected as low consistency piles by sonic integrity test. The pile number 92L2 was one of the piles detected as low consistency in bridge 92. According to the sonic integrity test results, three locations were selected for coring up to the rock level of 15m by the main contractor of the piling project (Figure 3). After completion of the coring works by GEC, holes were cleaned properly using high pressure air and water. During the cleaning works, it was observed that hole No.01, No.02 were interconnected and the hole No.03 was unaccompanied with others. One batch of grout mixture was prepared by mixing ordinary Portland cement bag (50kg) with 20l of water in the ratio of 1:0.4 by weight. Admixtures, 250 grams of Flow cable and 300 ml of Glenume C380 were used for each 50kg bag of cement to reduce the viscosity and increase the strength of the grout. The viscosity of the properly mixed grout was tested by marsh funnel and it was in the expected range. Injecting of grout was started with hole no.01 while others were kept open. It was observed that no pressure development for 12 minutes time and taken 8 batch of cement grout. When the same concentration grout came out from hole no.02, it was plugged. After that the pressure was gradually increased when cavities

Figure 3 - Pile Rectification
were filled. Grouting of hole no. 01 was terminated after 28 minutes using 18 batch of grout. It was maintained the maximum pressure of 17 bar for 10 minutes after no injection was recorded. Random samples were taken during the grouting work for cube crushing test. Hole no. 03 was grouted using a pipe inserting in to the bottom of the hole and subsequently removing the pipe with filling of the hole. After three days the pile was tested by an independent testing company using PDA with subsequent CAPWAP analysis and results showed that pile had achieved mobilised capacity of 1496 tonnes which exceeded the required load of 765 tonnes. The results had proved that the pile was successfully rectified and consolidated by the grouting process.

4.2. Case Study No. 02 - Multi Storied Building Complex, Narahenpita
Piling works of the multi storied building complex of labour department were carried out by a major piling company in Sri Lanka. GEC was selected for rectifying their low consistency piles in this project. The pile number P73L3 was one of the piles which was successfully rectified by GEC. After interpreting the sonic test results, two locations were selected for the coring and it was done by the GEC. It was observed that the two holes were interconnected. The main contractor had proposed expensive construction grout, water and nanocrete for the grouting works. However, GEC proposed ordinary Portland cement, water with admixtures and it was confirmed by testing the mixture and cube. One batch of grout was prepared by mixing 1:0.4 ratio of cement, water by weight adding 250g of flow cable and 300ml of Glenume for 50Kg of cement. Injection of grout was started with one hole while the other one was kept open. It was observed that no pressure development for 24 minutes time and taken 23 batch of cement grout. When the same concentration grouts came out from other hole, it was plugged. After that the pressure was gradually increased as cavities were filled. Grouting was terminated after 71 minutes using 52 batch of grout. It was maintained at the maximum pressure of 15 bar for 10 minutes after no injection was recorded. Random samples were taken during the grouting work for cube crushing test. After three days, the pile was tested by independent testing company using PDA with subsequent CAPWAP analysis and results showed that mobilised capacity of pile was exceeded the required load. The results were proved that the pile was successfully rectified and consolidated by the grouting process.

5. Conclusions
Pile rectification process is being increasingly adopted during last few years with the development of the construction industry in Sri Lanka. GEC has successfully conducted many pile rectification projects. It has proved that most suitable mix proportion for the pile rectification is 1:0.4 of cement and water by weight. The admixtures are essential to maintain the right viscosity and strength. After rectification works it is essential to carry out PDA with subsequent CAPWAP analysis to ensure that the pile has been successfully consolidated after the grouting.

6. References
Yung, Keung-Shing, (2001). Piling design and construction in Hong Kong