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CONCRETE FOR WET PROCESS BORED PILES

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ABSTRACT

The final quality of wet process bored piles is not only depending on the good construction practice of piling contractors but also on the characteristics of concrete supplied. The concrete characteristics are of the major items that influence the performance of piles after casting. Due to the nature and environment of wet process bored piling, both proper drilling and pouring of concrete would not produce the good quality piles, if the quality of concrete did not meet the basic characteristics required for bored piling process. This paper reviews the basic characteristics of concrete required in wet process bored pile and presents some example problems caused by improper concrete mix. Additionally, the problems caused by improper concrete pouring process and preventive measures are also described.

INTRODUCTION

The quality of piles depends on a good construction process including drilling, reinforcement installation and concrete pouring as well as on good quality of concrete. Quality of concrete has some influence on the workmanship with interrelated performances. For wet-process bored piles, concrete is cast under drilling slurry using tremie pipes. Good quality concrete in bored piling sense means that the properties and characteristics of the concrete are suitable for the process of work and subsequently meet requirements of the finished product. Continuous concrete pouring which is mandatory in piling and it is sometime disrupted by blockage of segregated or prematurely set concrete mix in the tremie pipe. Early setting of concrete after pouring in bored hole can also cause discontinuities in pile by accidental lifting of set concrete during extraction of the temporary casing. Dampness is sometimes found in top section of piles constructed in water-bearing permeable soil layer. The dampness was found to be caused by capillary action of ground water through interconnecting voids formed in the improperly mixed concrete.

Ready mixed concrete for bored piles usually specified as self-compacting concrete and its “compacting factor” is very important for achieving required strength, especially at the top section of pile which usually carries the maximum portion of transferred load. However, the compacting factor is seldom mentioned in piling practice. Besides, no vibration is allowed for tremie concrete while structural concrete is compacted by vibrator during casting. The concrete strength test is usually carried out on the compacted test samples and thus the actual strength of pile can be different from sample strength according to the compacting factor.

WET PROCESS BORED PILING METHOD

In wet process bored piling, bentonite or other type of suitable drilling slurry is used as drilling fluid to support the borehole during construction. A steel temporary casing is usually used to case the top weak soil subjected to heavy construction loads. Drilling and reinforcement cage installation and concrete placing are successively executed under drilling slurry. The concret is poured with tremie pipes, displacing the slurry well above the cutoff level. The temporary casing is then extracted immediately after concreting.

CHARACTERISTICS OF CONCRETE AND CONCRETE MIX

Concrete mix for bored piles is designed according to concrete pouring process and mechanical properties required. Concrete for wet process piles needs to be specially mixed having cohesiveness with high workability (high slump/excellent fluidity) which is not prone to segregation and retain it workability as far as possible throughout the tremie placing operation for the complete pour. Addition to those characteristics, compaction under self-weight, resistance to harsh environment, resistance to leaching, and appropriate strength are essential.

Workability

Excellent fluidity is essential that the concrete has the ability to flow readily through the tremie pipe, to flow laterally through a reinforcement cage and a high lateral stress against the sides of borehole. High workability is best achieved with rounded natural aggregates and natural sand in the mix.

Self Compaction

Compaction under self-weight is essential as vibration of concrete is impractical, except near the surface. The degree of compaction achieved is determined by the density ratio (the ratio of density actually achieved to the density of the same concrete fully compacted). The recommended compacting factor for the required workability of tremie concrete is 0.95 to 0.96 (Xanthakos 1994). Fresh concrete is usually placed through tremie pipes and displaces the slurry by gravity action only. In some cases, lack of self-compaction in the concrete will lead to defects, such as reversed “hanging up”, and “whirls” in the completed pile. If the initial shear of the concrete is very high, the flow is likely to restrain, resulting in bentonite trapped in areas not reached by the concrete (Xanthakos 1994).

Resistance to Segregation

The concrete mix should be cohesive and resistant to segregation, as improperly designed mixes will segregate during placement, resulting in inferior concrete containing honeycombs and high permeable zones within the pile shaft. Concrete that bleeds or disintegrates under the pressures of its own weight can also block the tremie pipe or accept bentonite.

Controlled Setting

The concrete must retain it fluidity thorough the depth of borehole during complete placement of the concrete in the borehole and attain an appropriate strength within a reasonable time after placement. Retarders are used to prevent premature stiffening of some cements or to delay stiffening under difficult placing conditions. The setting time must be checked against the time necessary to complete the placement. The retarders should be used under competent technical advice and after adequate testing.

Resistance to Aggressive conditions

The concrete should have high density and low permeability to resist the possible (chemical and physical) attack of an aggressive sub-subsurface condition. In some instances there is an underground flow of water that can cause a weakening of the concrete after it is placed, and a properly designed mix should be resistant to such flow. However, if the rate of ground water flow is substantial, a permanent casing will be necessary.

Good Mechanical Performance

The mechanical properties of hardened concrete can be satisfied in most instances. However, appropriate tensile strength for the concrete without reinforcement in piles and high level of bending and axial stress must be considered in some cases.

Reese and O'Neil (1988) emphasis that the design of the concrete mix must be given appropriate attention and the design of the mix is dependent strongly on the particular job, and the cement will be selected to be consistent with the design requirement. They observed that bleeding is not a problem for concrete mixes that are properly designed. The trial mix method is usually used in the laboratory. It is necessary to follow-up to see that the materials and proportions used by the batch plant are those of that are recommended. Inspection at the batch plant should include checking the nature, quantity and temperature of the components of the mix, the aggregates, cement, water, admixtures and of the completed mix for conformance with the specifications. For testing at the job site, the organization of the job must be such that time required to perform tests at the job site is kept to a minimum. Excessive job-site testing can lead to harmful effects. No delay in pouring should occur due to field test.

Adding of water to the concrete with very low slump on site to increase the workability can have detrimental effect of reducing the strength, compactability and impermeability of the concrete. The results of adding water could be a significant change in the characteristics of mix and the possibility of segregation as the pour is made. Segregation of concrete during pouring can also lead to increase in permeability of concrete, especially at the top section of piles due to upward migration of water in the concrete mix. Adding of water to the concrete on site must not be allowed unless specified.

Suggested concrete mix by Fleming & Sliwinski (1977) for bored piles cast under Bentonite was shown in Table 1 while range of cement content and water-cement ratio in general use for concrete mixes by Bartholomew (1979) is shown in Table 2.

Table 1. Suggested Concrete Mix for Bored Piles Cast under Bentonite (After Fleming & Sliwinski 1977)

Slump	>175 mm.
Water/Cement	Below 0.6
Aggregate Type	Natural round stone if possible, 20 mm. max. size
Sand Type	Natural and complying with zone 2 or 3 grading
Sand Content	30% to 45% of total aggregate weight
Cement Content	Not less than 400 kg./m^3
Admixture	The use suitable admixture which will improve the workability and extend the period during which such workability is maintained are to be advocated.

Table 2. Range of Cement Content in kg/m3 and Water Cement Ratio in General use for Concrete Mixes (After Bartholomew 1979)

Pile Type	Conditions		
	Normal	Moderately Aggressive	Highly and Very Highly Aggressive
Precast	450-475	450-475	450-475
	0.4 – 0.5	0.4	0.4
Bored Piles Dry Process	300-450	350-450	380-500
	0.5 – 0.55	0.475 - 0.5	0.45 - 0.5
Bored Piles with Tremie Process	350-450	350-450	400-500
	0.5 – 0.6	0.475 - 0.5	0.43 - 0.45
Driven Cast-In-Situ Piles	280-370	330-450	370-500
	0.25 – 0.6	0.3 – 0.55	0.3 - 0.45

Concrete for bored piles compared to that for pre-cast drive piles is the least dense concrete due to pouring and casting process. Bored pile concrete was cast in the aggressive subsurface conditions such as, high salinity, ground water fluctuation or in the vicinity of sea and river. In such environment, the concrete can easily be leached out by ground water. In this case cement content and water cement ratio given in the Table 2 needs to be reviewed considering the site conditions.

Fleming et al (1977) pointed out that the high cement content favored for in-situ pile construction enable the necessary workability mixes to be used with adequate margins of safety against the inevitable variations in strength and workability. It also compensates for some reduction in strength, which may occur on interfaces during displacement.

Concrete is permeable to water to the extent that it has interconnecting void spaces through which water can move. Calcium hydroxide liberated by hydrating cement is water-soluble and may leach out of harden concrete, leaving voids for the ingress of water. Permeability of concrete is governed by amount of cementitious material, water content, aggregate grading, consolidation and curing efficiency.

MEHTOD OF CONCRETE POURING

The quality of piles depends on a good pouring procedure as well as on good quality of concrete. In wet process, the concrete is usually placed by a steel tremie pipe of 20-25cm in diameter (minimum 6 times of coarse aggregate size).

Prior to charging the tremie pipe with concrete, the bottom of tremie needs to be sealed by a plug of some descriptions may be inserted at the top of tremie before or after the tremie is placed in the bored hole as appropriate. There are two potential problems that are associate with the initial charging of tremie with concrete; the concrete can segregate during placement and the air in tremie will prevent the complete filling of the tremie. These problems can be avoided if the tremie is filled slowly. Faulty initial charging of tremie during concreting can cause entrapment of mud within the concrete.

Excessive initial lifting of tremie can result in possible distribution of leached concrete caused by concrete falling through the slurry. The bottom of tremie must stay well below the top of the column of fresh concrete all the time. Moreover, the tremie must not be lifted and lowered rapidly to avoid the cause of contamination of concrete with slurry. It is suggested that the tremie pipe must not be lift and lowered rapidly to start or restart the flow of the concrete (Reese & Neil 1988). However Xanthakos (1994) suggested that if the concrete is not deposited easily the triemie pipes may be moved up and down with movement not exceeding 30cm. Moreover, the tremie pipes should not be moved horizontally.

In the area of high ground water level, the concrete must be deposited above the external water table before the casing is withdrawn. The hydrostatic pressure in the concrete column should be greater at all time than the pressure in any column of fluid outside the casing.

COMMON DEFECTS

The common defects of piles are cold joints, zone of segregated or contaminated concrete, trapping of bentonite mud and cavities. The first two types of defect result from interruptions in the concrete placement or premature extracting of the tremie pipe either partially or completely above the concrete-slurry interface. Mud trappings are caused by concrete of low workability and impediment to the flow of concrete due to closely spaced bars. Discontinuities or partial separation in the piles at the bottom edge of temporary casing can be caused by accidental lifting of low workability concrete or concrete without controlled setting during casing extraction. If the concrete in the casing is too stiff and has considerable frictional resistance against the casing, a column of concrete can be pulled up with the casing.

Permeability of concrete depends on the capillary porosity, water-cement ratio and degree of hydration. High permeability of concrete can be contributed by presence of capillary pores that are interconnecting voids in the concrete (Figs 1 & 2). The interconnecting voids are caused by bleeding of concrete due to excessive water used in the mix. Bleeding raises the water and air bubbles to top surface of fresh concrete and raises the water-cement ratio of concrete upper part of the forms, thereby reducing the strength and increasing porosity of concrete. Concrete mixed with a water-cement ratio higher than 0.6 can be more permeable. Function of concrete self-compaction can also reduce the permeability and increase the density. In piles, usually the fresh concrete compacts under its own weight, resulting in an increasing density with depth. Besides, concrete in a great depth of pile is generally cured in stable temperature and moisture.

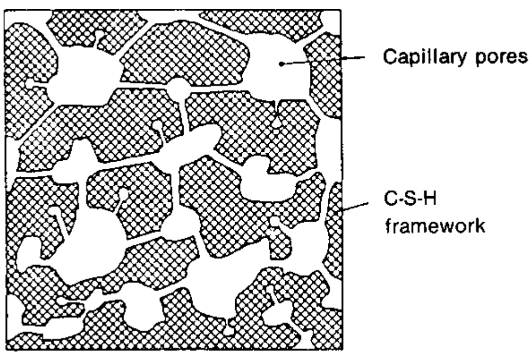

Figure 1. High permeability of concrete caused by interconnecting voids

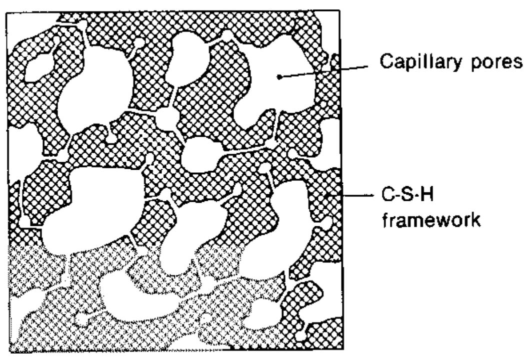

Figure 2. Low permeability of concrete caused by less interconnecting voids

Usually one type of concrete mix is used for piling in a particular project in most cases. However, the project in the vicinity of the river, some bored piles are to be installed closer to the river than the remaining piles and thus the concrete mixes need to be designed accordingly. For the piles installed in the deposition side of the river where sand deposits occur, these piles are usually subjected to be effected by the ground water flow (Fig. 3). If the cement content is not high enough in the concrete mix and bleeding or segregation occurs, dampness or wet patches caused by capillary suction to ground water through the previous tremie location and vertical steels can be found on the pile head (Figs 4 & 5). Figure 6 is a photo of core sample obtained from the pile that exhibits the dampness on top, showing segregated concrete caused by bleeding.

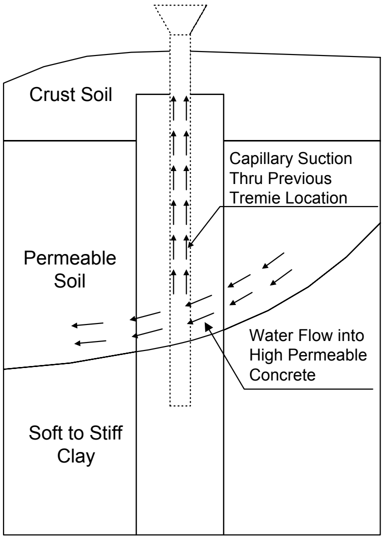

Figure 3. Capillary flow of ground water in bored pile

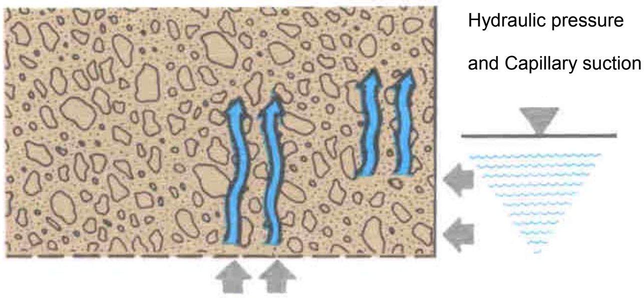

Figure 4. Capillary suction and hydraulic pressure in concrete

Figure 5. Wet pile head caused by capillary flow of ground water through segregated concrete in the pile

Figure 6. Core samples showing segregated concrete in the pile

Figure (7) show the some segregated concrete extracted from the tremie pipe, which was blocked with such concrete. Settlement of solid particles or aggregates in the concrete mix cause bleeding by migration of the water to the top surface of fresh concrete, reducing water-cement ratio of the lower part of the mix. As a result, lower part of the concrete mix stiffens rapidly with aggregates. In such case stiffening concrete can also block the tremie pipe during concrete pouring (Fig. 8) causing disruption in casting process and thus effects the quality of pile. Equipment for concrete pouring must also be adequate and reliable to avoid any interruption due to a breakdown in continuous tremie concrete pouring operation.

Figure 7. Tremie blocked by segregated concrete.

Figure 8. Tremie blocked by stiffening concrete

Due to a congested bar arrangement, concrete cannot flow through the bars and as a result concrete cover can be lost. Good arrangement of reinforcing bars is thus necessary. The horizontal spacing of main bars should be at least 10cm and 15cm (minimum 4 times of the maximum size of aggregate) for small and large diameter bars respectively.

RECOMMENDATIONS AND CONCLUSIONS

Foundation designers and concrete suppliers should pay more attention to workability and many other important factors required for cast in-situ tremie concrete than strength alone. It is essential to design the better quality mix than the concrete for other structural works in some aspects, considering the process of work.

For the projects, such as elevated highways, viaducts and bridges, variable soil and ground water conditions can be encountered along the project area. In such cases, concrete mixes need to be designed to suit these conditions and used accordingly in bored pile construction.

An adequate cement content and water cement ratio is necessary to have good impermeability of concrete which is one of factors influencing the durability of concrete, especially for bored piles in water bearing subsoil.

It is concluded that appropriate concrete mix and casting practice is essential in bored piling work to achieve good quality piles.

REFERENCES

Bartholomew, R. F. (1979), The Protection of Concrete Piles in Aggressive Ground Conditions: An International Appreciation", Proceedings of the Conference on Recent Developments in the design and Construction of Piles, ICE London, 21-22 March 1979, pp. 131-141

Fleming, W. K. and Sliwinski, Z. J. (1977), "The Use and Influence of Bentonite in Bored Pile Construction", CIRIA Report . PG. 3.

Reese, L. C. & O' Neil, M. W. (1988), Drilled Shafts: Construction Procedures and Design Methods, U.S. Department of Transportation, Federal Highway Adminstration, Virginia incorporation with ADSC., Dallas, Texas, USA.
Xanthakos, P. P (1994), Slurry Walls as Structural systems, 2nd Edition, McGraw-Hill Inc.