The effect of site practices on the integrity of large diameter bored piles

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ABSTRACT

In South Africa, concrete in large diameter bored piles is generally placed by discharging a high flow concrete mix directly from the truck mixer and allowing the concrete to fall freely to the base of the pile hole. While certain site practices have been used by piling contractors for years, many engineers are not convinced of their acceptability. This paper discusses the results of an investigation which assessed the effect of site practices on the integrity of cast *in-situ* bored piles. Such practices include the method of concrete placement and the amount of water and/or loose spoil in the pile hole at the time of casting. The results of this investigation dispel the myth that the free fall placement of concrete in clean, dry pile holes has a detrimental effect on the degree of compaction and compressive strength of the concrete.

RÉSUMÉ

En Afrique du Sud, le béton dans les pieux forés de grand diamètre est placé en renvoyant directement de haut un mélange de béton par écoulement direct d’un camion mixeur permettant ainsi au béton de tomber librement à la base du pieu. Pendant que certaines methodes ont étées utilisées des années durant par des entrepreneurs, beaucoup d'ingénieurs ne sont du reste pas convaincus de leur acceptabilité. Cet article discute de resultats d'une enquête menée pour évaluer les effets pratiques sur l'intégrité de couler in-situ le béton dans les pieux forés. De telles pratiques incluent la méthode de placement du béton, la quantité d’eau dans le pieu au moment de la coulée et la propreté de la vrille de forage. Les résultats de cette enquête dissipent le mythe selon lequel le placement par chute libre du béton dans les pieux forés, propres et secs, a un effet préjudiciable sur le degré de compaction et sur la force de compression du béton.

1 INTRODUCTION

Large diameter bored (augered) piles are ideally suited to stable residual soil profiles and deep water table conditions frequently, encountered in the inland regions of South Africa. In many areas of the country, holes can be augered without the need for temporary casing, safely cleaned by hand and inspected *in-situ* prior to the insertion of the reinforcing cage and placement of concrete. Typically, piles are cast by discharging high flow concrete directly from the chute of the truck mixer using the deflector flap at the end of the chute to direct the stream of concrete down the centre of the reinforcing cage in a continuous stream.

Most piling specifications and construction drawings clearly specify the class of concrete and the nature of the founding material for cast *in-situ* bored piles. However, in most instances, little or no attention has been paid to site practices which can have a significant effect on the integrity of the pile. These include the method of concrete placement, the amount of water in the pile hole at the time of casting and the cleanliness of the pile socket. The few documented case histories where problems have been experienced with this technique are generally associated with the presence of water or spoil at the bottom of the hole at the time of pouring the concrete.

The main objectives of this research were to investigate:

Whether the free fall or slow pour placement methods result in a loss of strength or in segregation,

The extent to which the presence of water in the pile hole affects the strength of the concrete, and

What happens to any spoil remaining in the bottom of the pile hole during concrete placement and how this affects the integrity of the pile shaft?

This paper describes the procedures used during the tests and summarises the results obtained.

2 CODE OF PRACTICE REQUIREMENTS

2.1 South African Codes

There appears to be a vast discrepancy between acceptable practice in structural concrete engineering and that in the piling industry.

Most codes of practice for structural concrete lay down strict requirements for the placing of concrete.

Many of these requirements are aimed at preventing segregation and ensuring adequate compaction of the concrete. SABS 1200 G (1982) requires that concrete shall not be allowed to fall freely through a height of more than 3 m unless otherwise approved and that compaction of the concrete is carried out by mechanical vibration. These requirements frequently find their way into piling specifications where completely different circumstances prevail.

SABS 1200 F-1983 (Piling) specifies a concrete slump of between 75 mm and 175 mm for various conditions depending on the method of placement, spacing of reinforcement and diameter of the pile hole. The code recommends that internal vibrators should not be used, that concrete should be placed in the dry or by means of a tremie, that concrete be placed in such a way that segregation does not occur and advocates the use of a chute extending far enough into the hole to ensure that the concrete drops vertically when leaving the chute. In the case of raking piles, the chute is required to extend to the leading edge of the newly placed concrete.

Read together, these clauses from SABS 1200 F (1983) imply that the free fall placement of concrete is permitted in vertical pile holes provided that the concrete is permitted to fall unobstructed down the centre of the pile.

2.2 ACI Manual of Concrete Practice: Concrete Piles

The 1973 version of the ACI manual permits the placement of pile concrete, at a continuous and rapid rate, from the top of the hole but only through a funnel hopper having a discharge opening smaller than the smallest pile section. Furthermore, the pile hole is to be free of all foreign matter including “appreciable quantities of water”. Vibration of concrete is recommended for internally reinforced piles.

Of all the manuals and specifications, the 1973 ACI Manual accords closest with common practice in the piling industry. The only significant difference is the recommendation that the concrete in internally reinforced piles be compacted by means of vibration.

In editions of this document published in 2000 and subsequent revisions these clauses have been moved and re-titled. Unfortunately, the clauses relating to methods of placement have been omitted in the 2000 and later versions of the ACI document.

3 EXPERIMENTAL METHODS

3.1 Construction of Piles

During the field work phase of the programme, a number of trial “piles” were cast using free fall placement of concrete with various amounts of water and/or spoil at the bottom of the pile hole. The “piles” consisted of 200 litre steel drums placed at the bottom of a 6 m deep, 1,5 m diameter auger hole. The drums had a diameter of 560 mm and depth of 870 mm. A 50 mm thick concrete blinding layer was cast at the bottom of each drum and allowed to cure, to provide a solid base onto which the pile concrete could be cast. Before lowering the drums into the hole, measured amounts of water and/or spoil were placed into the drums to simulate inadequate cleaning of the pile.

Two types of spoil were used, one slightly cohesive and the other granular. The first was a silty andesite taken from the spoil of other pile holes being drilled on the site. This material classified as ML according to the Unified Soil Classification System, i.e. a silt of low plasticity. The second material was a crusher dust which classified as SW/SM, i.e. a well graded silty sand.

Concrete was discharged into the drums through a 500 mm diameter light weight steel casing inserted about 100 mm into the top of each drum in turn as shown in Figure 1. On completion of the pour, the drums were lifted from the hole and left to cure on surface.

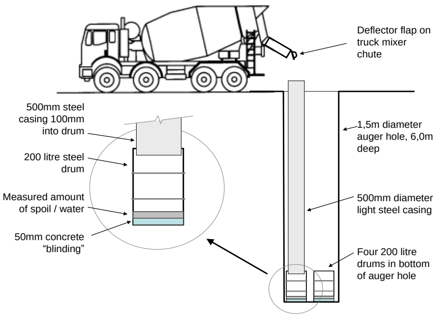

Figure 1. Method of casting test “piles”

During casting, the concrete was directed down the centre of the casing using the deflector flap at the end of the chute of the truck mixer. The main stream of concrete reached the bottom of the “pile” without impinging on the sides of the casing. The rate of pour was rapid and the drop height was 6,8 m to the bottom of the pile.

In the penultimate test, holes were cut through the casing and reinforcing bars were inserted horizontally across the casing to break the free fall of the concrete and encourage segregation. The concrete was discharged at the same rate as was used for the other tests.

In the final test, the concrete was poured slowly, falling from the chute of the truck mixer as individual blobs.

3.2 Mix Design

The mix proportions of the concrete, which was supplied by a ready mix company, are included in Table 1.

Table 1. Concrete mix design

Characteristic Strength (MPa)	25
Target Slump (mm)	100
Sand (dry) (kg)	795
Stone (19 mm) (kg)	1090
CEM III A (50/50 CEM I/ Slag) (kg)	335
Water (litres)	200

The tests made use of four batches of the concrete delivered to site by separate truck mixers over the two day period. Control samples of concrete were taken from each truck by casting concrete into drums on the surface and compacting the concrete by mechanical vibration.

The degree of control exercised over the batching is questionable as the slump of the concrete delivered to site varied from 50 mm to 200 mm and the cube strength of the control samples varied from 35 MPa to 47 MPa with an average of 37 MPa.

3.3 Sampling, Testing and Visual Inspection

Approximately two weeks after casting of the “piles”, the drums were turned over and 100 mm diameter and 300 mm long core samples were drilled (vertically) through the bottom of each drum. After visual inspection and photography, the cores were submitted to an accredited commercial laboratory for testing.

Compressive strength tests were carried out on all core specimens at an age of 37 or 38 days after casting, in accordance with the recommendations contained in CSTR (1987). Prior to testing, the cores were prepared by grinding their ends until smooth and subsequently capping them with a sulphur mortar which comprised (by mass) 2 % carbon black, 49 % fine sand (150 to 300 microns in size) and 49 % sulphur. This mixture was heated to a temperature between 230 °C and 250 °C before being applied to the cores. The average strength of the set capping mortar was approximately 250 MPa. The length of the capped cores exceeded the diameter by 2 to 5 mm. The frictional effects resulting at the end of the cores during testing were negligible and hence were ignored.

The percentage of excess voids was assessed visually, according to the method in CSTR (1987).

The aggregate: binder ratios were determined on nine samples of concrete cast through various depths of water and on one of the control samples using the soluble silica test method, as detailed in BS 1881: Part 124: 1988.

After the concrete cores had been taken, the bottom of the drums containing spoil (at the bottom of the “pile hole”) were cut away to observe the extent to which the spoil had been displaced by the falling concrete. After removal of the layer of blinding concrete, the area of intimate contact between the pile concrete and the bottom of the hole (i.e. the area over which the spoil had been completely displaced) was estimated.

4 RESULTS

Table 2 summarises the conditions under which the various “piles” were concreted and laboratory test results.

5 DISCUSSION

This section of the paper discusses each of the research objectives (listed earlier) in turn.

5.1 Segregation Due to Free Fall Placement

Figure 2 show cores drilled through the bottom of the “piles” cast through various depths of water in the pile hole at the commencement of the pour. Variations in the length of these cores are merely attributed to the breaking of the core from the surrounding concrete.

Figure 2. Concrete cores from concrete cast into water in pile holes

In this figure, the bottom of the core is facing away from the reader. The contact between the 50 mm blinding concrete cast in the drums and the “pile” concrete is visible in some of the cores.

In all these cores, there was an even distribution of aggregate, despite the apparently higher void content of the concrete for greater water depths. A similar, even distribution of aggregate was observed in Test R1 which simulated the effect of allowing concrete to impinge on the reinforcing cage during free fall into 100 mm of water. The only case where segregation was evident was where the concrete was poured slowly into 100 mm of water as shown in Figure 3.

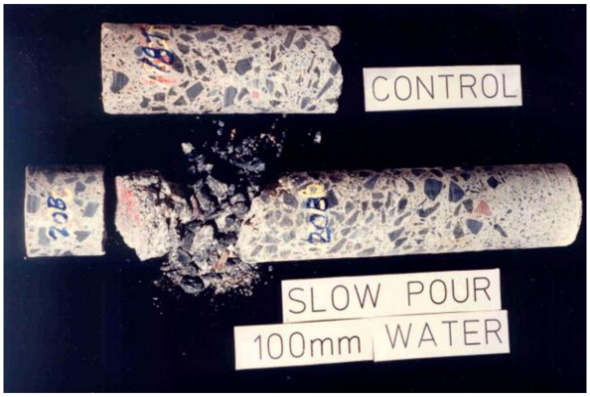

Figure 3. Segregation of concrete poured slowly into 100 mm of water.

Table 2. Summary of concrete core test results

Test Ref.	Sample Ref.	Concrete Batch	Compressive Strength (MPa)	Compressive Strength (% of control)	Excess Voids (%)	Aggregate/ Binder Ratio	Test Conditions
C1	7B*	C1	51,0	100	0,0	9,5	Control test, vibrated
C2	7T*	C2	39,0	100	0,0		Control test, vibrated
C3	18B	C3	43,0	100	0,0		Control test, vibrated
C4	18T	C4	40,5	100	0,0		Control test, vibrated
W1	3B	C1	48,5	95	1,0	9,2	Free fall, dry
W2	13B	C4	48,5	120	1,5	11,9	Free fall, dry
W3	1B	C1	37,5	74	0,5	9,3	Free fall, 50mm water
W4	6B	C2	38,0	97	0,5	9,0	Free fall, 50mm water
W5	2B	C1	25,0	49	0,5	7,6	Free fall, 100mm water
W6	8B	C2	23,5	60	1,0	12,2	Free fall, 100mm water
W7	4B	C1	9,0	18	3,0	13,2	Free fall, 200mm water
W8	9B	C2	8,5	22	4,0	14,4	Free fall, 200mm water
W9	5B	C2	7,0	18	10,0	16,9	Free fall, 400mm water
W10	12B	C3	10,0	23	15,0		Free fall, 400mm water
S1	10B	C3	50,0	116	0,5		Free fall, 50mm silt, dry
S1	10T	C3	42,0	98	1,5		Free fall, 50mm silt, dry
S2	11B	C3	21,5	50	1,0		Free fall, 50mm silt, 100mm water
S2	11T	C3	22,0	51	1,0		Free fall, 50mm silt, 100mm water
S3	17B	C4	48,5	120	1,5		Free fall, 50mm silt, 50mm water
S4	14B	C4	50,5	125	2,0		Free fall, 50mm c.dust**, dry
S5	15B	C4	46,0	114	1,5		Free fall, 50mm c.dust, 50mm water
S6	16B	C4	31,0	77	1,0		Free fall, 50mm c.dust, 100mm water
R1	19B	C4	25,5	63	1,5		Free fall, with rebar, 100mm water
R2	20B	C4	20,0	49	1,5		Free fall, slow pour, 100mm water

Notes: *T indicates top of drum, i.e. about 800mm above bottom of pile

*B indicates bottom of drum, i.e. at bottom of “pile”

**c.dust indicates crusher dust (sandy fines from crushed aggregate).

In Figure 3, the bottom of the core is to the left of the picture. The disk of blinding concrete has separated from the pile concrete. The pile concrete shows classical signs of segregation, with unbonded aggregate at the toe of the pile and decreasing aggregate content with the accumulation of fines and laitance towards the top of the pour.

From these observations it was concluded that the pouring of concrete at the normal (rapid) rate resulted in sufficient turbulence at the bottom of the hole to prevent segregation of a self levelling, high slump concrete mix even where the fall of the concrete was interrupted by impact with the reinforcing steel. This confirms the findings of separate studies carried out by STS Consultants (1994) and Turner (1970). However, where the concrete was poured slowly, this turbulence was absent and no re-mixing occurred at the bottom of the hole. Where water was present, the fine aggregate and cement paste were removed by the upward percolation of water through the concrete leaving un-bonded coarse aggregate at the bottom of the hole.

5.2 Effect of Water in Pile Hole

The effect of the depth of water in the pile hole prior to commencement of concreting on the strength of the concrete is shown in Figure 4. An exponential curve was fitted to the data.

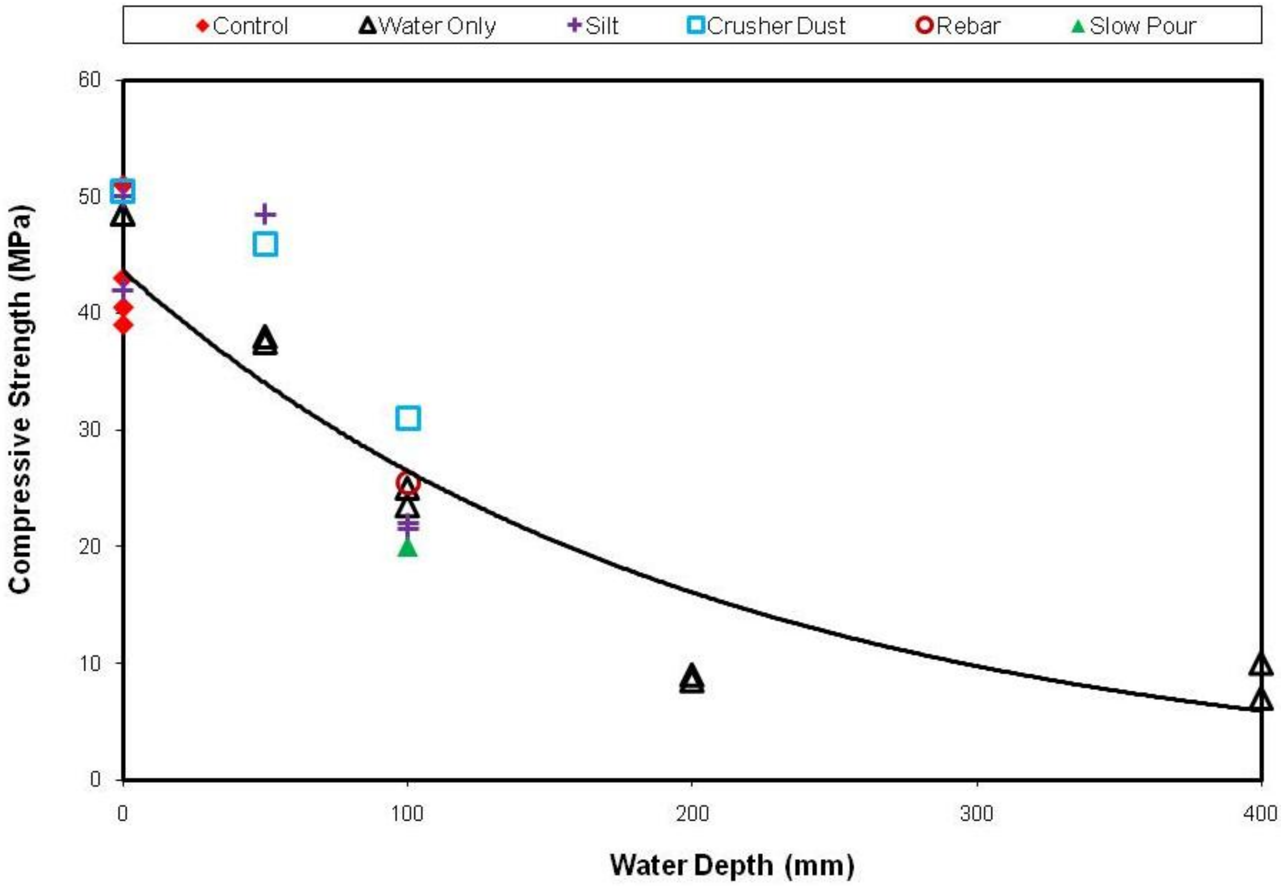

Figure 4. Effect of water depth on compressive strength

Figure 4 clearly demonstrates the adverse effect which casting of concrete into water has on concrete strength. As little as 100 mm of water in the bottom of the pile hole resulted in an approximately 50 % decrease in the strength of the concrete. For water depths in excess of 200 mm, the concrete strength was reduced by approximately 80 %. Further increases in the amount of water in the bottom of the pile hole appear to have little effect. This was probably caused by the concrete not being able to absorb the excess water which was carried upwards during pouring of the concrete.

The samples containing crusher dust “spoil” generally achieved higher strengths at the relevant water contents. This was probably the result of the crusher dust mixing with the concrete and any water present, on impact, as the concrete was poured, hence reducing the formation of voids. However, this was not the case in the samples containing silt “spoil”.

With reference to Table 2, tests were performed on cores taken from both the top and bottom of drums 10 and 11. It is interesting to note that the strength of the top and bottom cores from drum 11 only differed by 0,5 MPa. However, in the case of drum 10, the strength of the bottom core exceeded that of the top core by 8 MPa. The latter result was expected due to bleeding of the concrete. With the methodology employed, it was not possible to investigate the persistence of this effect up the length of the pile shaft or to assess any increase in bleeding of the concrete with the increase in the amount of water in the hole.

The inclusion of reinforcing appeared to have no effect on the strength whilst the slow pouring resulted in a slight reduction in strength.

No trend was identified when comparing the results deriving from each of the control samples. The correlation shown in Figure 4 was not improved when normalising the compressive strength by expressing it as a percentage of the compressive strength of the relevant control sample.

Figure 5 indicates that the percentage excess voids increases with depth of water. In view of the fact that the control samples were vibrated, these samples were appropriately excluded from the relationship. An exponential curve was fitted to the data.

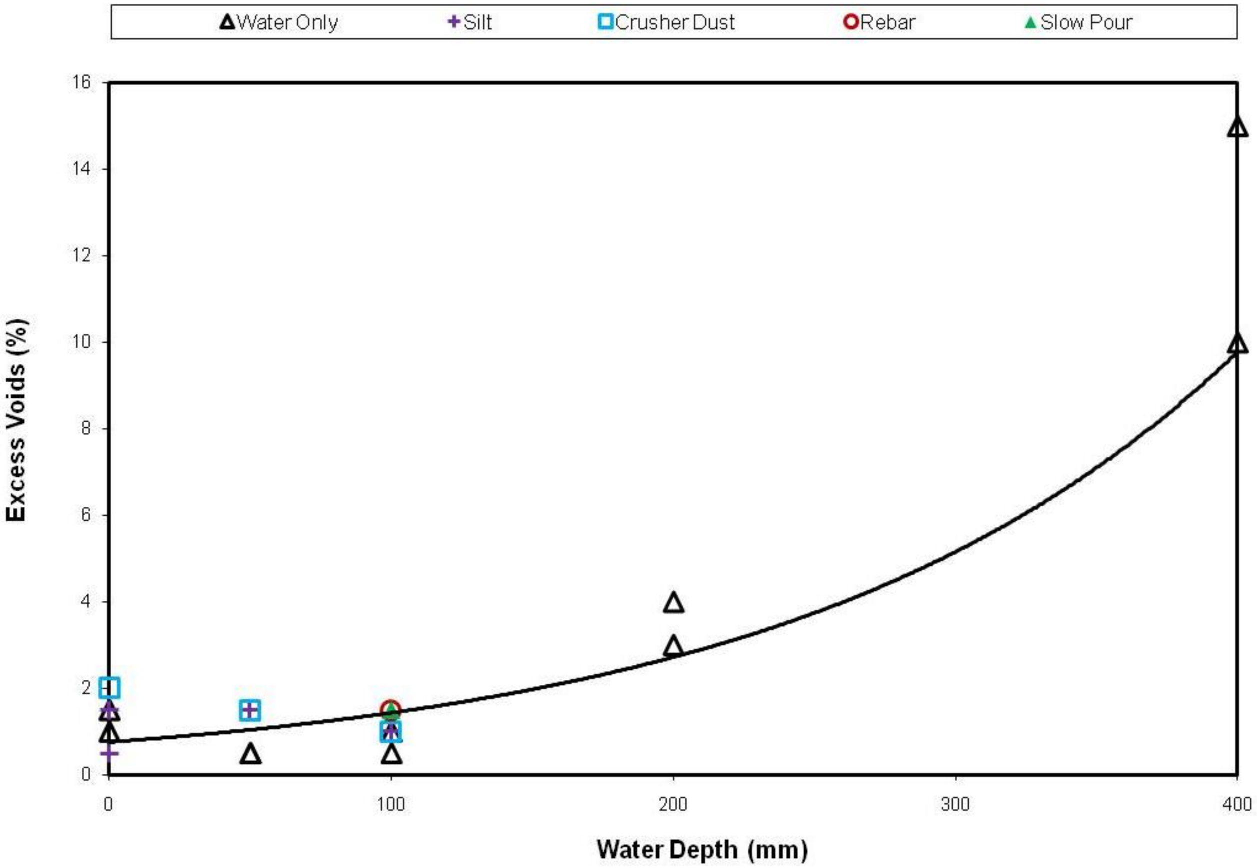

Figure 5. Effect of water depth on percentage excess voids

Referring to Figure 5, for water depths of less than 100mm, the excess voids were typically less than 2 % and are thought to be due to the entrapment of air. However, as the depth of water increased, the excess voids increased to between 10 % and 15 %. The reason for this trend is that the water at the bottom of the pile hole, due to its relatively low density, rose into the concrete (during pouring) displacing the mortar and creating voids. Hence, the greater the volume of water in the pile hole, the greater the volume of excess voids in the concrete.

Note that, in Figure 5, the data point for the slow pour (triangle) is located in the rebar symbol (circle).

Referring to Table 2, it is evident that in the case of cores W1, W3 and W5, which derived from Concrete Batch C1, the excess voids of the core from the dry pile hole exceeded those of the piles containing 50 and 100 mm of water. Although the reason for this trend is not clear, it may be attributed to a reduction in the viscosity of the concrete mix with the addition of 50 to 100 mm of water.

In contrast to Figure 4, however, no tailing off was evident with water depths in excess of 200 mm. The increase in voids with increasing water depth is clearly visible in the photograph in Figure 2 where, for water depths of 200 mm and 400 mm in particular, the matrix to the coarse aggregate appears to have been eroded during the drilling operation giving visual confirmation of the low strength of the paste.

Figure 6 shows the correlation between the depth of water in the pile hole and the aggregate: binder ratio. A straight line was fitted to the data using the least squares method.

For water depths of less than 100 mm, the average aggregate: binder ratio was of the order of 10. However, this increased to as much as 17 where the concrete was placed through 400 mm of water. This trend is attributable to the upward displacement of mortar, from amongst the coarse aggregates in the lower section of the pile hole, caused by the upward movement of water through the concrete during pouring. Hence, the more water present, the more mortar displaced.

With reference to Table 2, in the case of cores W3 and W5 (which derived from Concrete Batch C1) an increase in the water in the bottom of the pile hole resulted in a decrease in the aggregate: binder ratio. There is no obvious explanation for this unexpected result.

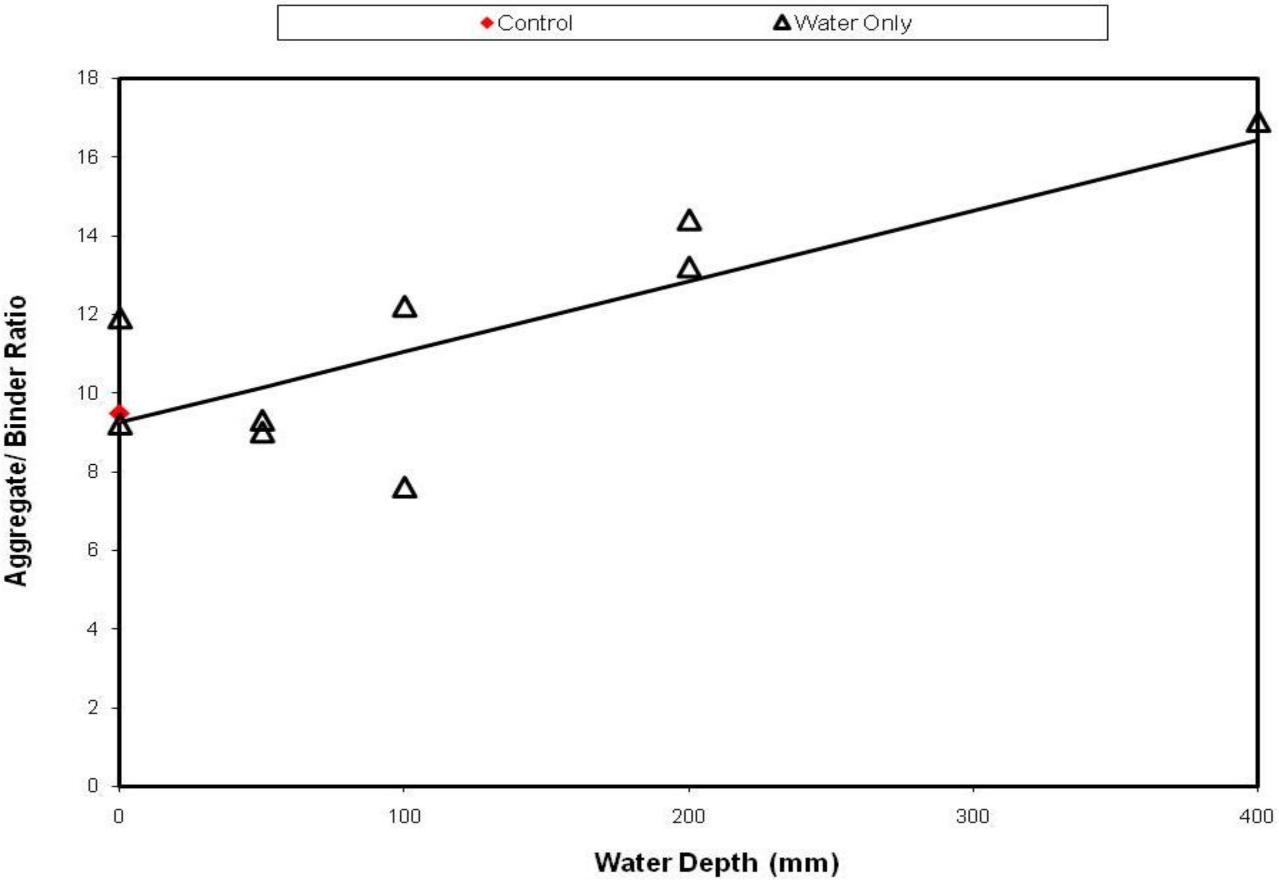

Figure 6. Effect of water depth on aggregate: binder ratio

5.3 Displacement of Spoil

As shown in Table 2, the bottom of pile holes for tests S1 to S6 contained 50 mm of spoil. By cutting away the bottom of these drums, the percentage of contact between the pile concrete and the blinding was estimated and the distribution of spoil was observed.

Table 3 shows the percentage of the area of the base of the pile which was in intimate contact with the bottom of the pile hole (i.e. the area over which the spoil had been displaced). Higher percentage contacts are more favourable from a founding point of view.

In the case of both the silty spoil material and the crusher dust, casting of concrete onto 50 mm of dry spoil resulted in total separation between the pile concrete and the base of the pile hole. However, the contact area increased to between 40 % and 60 % in the tests where 50 mm or 100 mm of water was added to the base of the pile hole together with the spoil

Figure 7 shows the contact between the blinding concrete at the base of the drum (representing the *in-situ* founding material) and the pile concrete for piles cast onto 50 mm layer of crusher dust at the bottom of the pile hole.

Table 3. Area of base of pile in intimate contact with the bottom of the pile hole

Test	Test Conditions	Base Contact (%)
S1	Free fall, 50mm silt, dry	0
S2	Free fall, 50mm silt, 100mm water	60
S3	Free fall, 50mm silt, 50mm water	40
S4	Free fall, 50mm c.dust, dry	10
S5	Free fall, 50mm c.dust, 50mm water	60
S6	Free fall, 50mm c.dust, 100mm water	50

Figure 7. Close up of contact between "pile" concrete and blinding concrete for piles cast with a 50 mm layer of crusher dust at the bottom of the pile hole

The dry crusher dust (0 mm water – left core sample) was trapped between the pile concrete and the bottom of the pile hole resulting in a total loss of contact of the pile with the founding material. With 50 mm of water in the pile hole, the crusher dust over the middle of the hole was displaced by the falling concrete and this material was assimilated into the pile concrete as a result of the remixing of the concrete as it fell to the bottom of the hole. With 100 mm of water in the hole, the contact over the central portion of the pile was tight. However, the strength of the pile concrete had reduced to 77 % of that of the control sample (40,5 MPa to 31 MPa) and the bearing area was reduced by about 50 % due to trapping of crusher dust around the perimeter of the pile base.

6 CONCLUSIONS

On the basis of the above experimental data, the following conclusions were reached:

No segregation of the concrete (in the sense of an accumulation of aggregate at the base of the pour) was observed when the concrete was discharged from the truck mixer at a rapid rate even when the concrete was permitted to impinge on the reinforcing "cage". Clear signs of segregation were evident when the concrete was poured slowly into 100 mm of water. It appears that the rapid discharge of concrete results in "remixing" of the concrete in the bottom of the pile hole.

Free fall placement of concrete into dry pile holes had no apparent effect on the compressive strength of the concrete compared to that of the four control samples.

Casting of concrete through 50 mm of water at the bottom of the pile hole reduced the compressive strength by an average of approximately 15 %. Casting of concrete through amounts of 100 mm and 400 mm of water in the bottom of the pile hole significantly reduced the compressive strength of the concrete by approximately 50 % and 80 %, respectively.

In addition to having an adverse effect on the strength of the concrete, casting of concrete into more than 100 mm of water was detrimental to the percentage excess voids and the aggregate: binder ratio.

As little as 50 mm of dry spoil at the bottom of the pile hole negated all direct contact between the pile concrete on the underlying founding stratum. Wet spoil was more readily displaced by the concrete but still resulted in significant reductions in base bearing area mainly around the perimeter of the pile base.

Interruption of the free fall of the concrete by a moderate amount of reinforcement appeared to have a negligible effect on the quality of the concrete, provided the rate of pour was reasonable.

On the strength of this limited research, it was concluded that the current practice of free fall placement of concrete in clean, dry pile holes has no detrimental effect on the quality of the concrete. It is, however, recommended that such techniques should not be used when the depth of water at the bottom of the pile hole exceeds 75 mm.

ACKNOWLEDGEMENTS

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