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Influence of concrete structural buildup at rest on the penetration of reinforcement cages in piles

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***Abstract*—The research presented here focuses on installation problems experienced during pile-driving operations using hollow auger. One cause of such problems is the fresh concrete behavior in place. The objective of this work is to define a property measurement of the concrete material and prepare a simple test to ensure the insertion of a reinforcement cage into fresh concrete without jamming and the appropriate concreting of a pile.**

***Mots clés*—foundations, rheology, concrete, piles, reinforcement.**

I. Introduction

The primary concern of any builder is to avoid the appearance of disorders related to an inadequate load-bearing base layer, which could undermine proper use of the completed structure. Consequently, foundations remain a key element in any construction project. One of the execution processes calls for laying special foundations by means of piles. The advantage of this technique is a quick and economical boring step. This category of pile, which can be driven using an auger, is the most widespread due to its suitability for the majority of ground conditions.

During on-site driving of these piles (see Fig. 1), contractors experience a number of difficulties that can be classified according to the various phases:

- Phase 1 - during boring: jamming of the drill bit ;
- Phase 2 - during concreting: plug formation at the time of concrete pumping, segregation problems, bleeding, soil inclusions in the concrete, loss of laitance ;
- Phase 3 - during placement of the reinforcement cage: difficulties in introducing the cage.

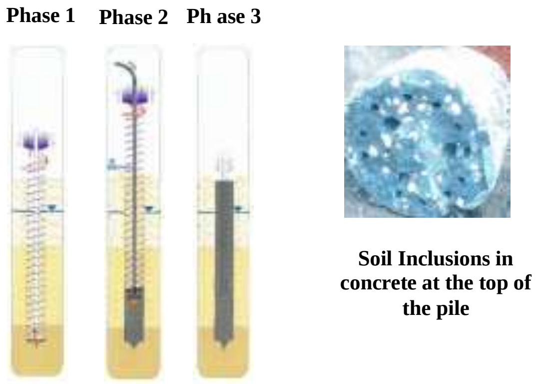

Figure 1. Installation of piles driven with a hollow auger and problem encountered

This article mainly discusses one such implementation problem, namely the difficulty encountered when introducing a reinforcement cage into fresh concrete. For now, no test or guideline is available regarding concrete that would ensure its successful placement in the presence of a pile whenever a reinforcement cage needs to be installed.

To solve this problem, a simple test of the capacity of reinforcements introduced into the concrete has been devised.

Next, a direct correlation may be drawn between the rheological properties of a common concrete mix design used for piles in the Nord-Pas de Calais region of France and the penetration capacity of reinforcements in fresh concrete. The long-term objective of this research is to establish recommendations for the mix design of a successful pile concrete.

II. Concrete mix design

A common concrete mix design for piles in the Nord-Pas de Calais region (see Table I) has been studied. This class S4 concrete complies with the NF EN 206-1 Standard. The targeted consistency of the pile concrete at on-site delivery is 22 cm.

The cement used is CEM III A 42.5 N LH PMES CP1 NF, which proves to be particularly well adapted for foundation-related works; it is composed of 62% blast furnace slag and 35% clinker, containing 60% C3S, 8.5% C3A and 11% C4AF. Its Blaine specific surface area equals 4 200 m2/kg.

The aggregates introduced have been fractionated into three classes: two 0/4 sands (one rolled siliceous variety and another crushed limestone), and a 6/12 fine gravel and 6/20 gravel, both of which composed of crushed limestone. The mass densities and absorption coefficients of these aggregates are listed in Table I.

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TABLE I. CONCRETE MIXTURE

	BPS-XA1-C30-S4-D20						
	Cement	***Water***	***Sand Gand***	***Sand Gau***	***Gravel 6/12,5***	***Gravel 6/20***	***Plastici-zer***
Proportion kg/m^3	350	190	415	415	300	590	1.4
ρ^a kg/m^3	2.95	-	2.65	2.60	2,75	2.78	1.20
a^b (%)	-	-	0.3	1.5	0.5	0.5	-

a. Density, b. Water absorption value

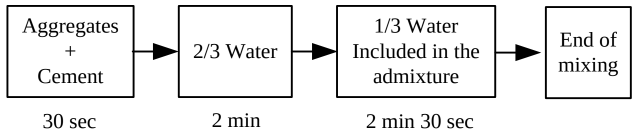


Figure 2. Mixing process

POUZZOLITH 399 N has been added to the basic mix design as a water-reducing plasticizer; it is a polycarboxylate-based liquid admixture.

A vertical shaft mixer, of the DIEM DZ 120V type, was used to produce the 45-liter batches in accordance with the mixing protocol described in Figure 2.

III. Rheological characterization of the concrete material

When placed at rest in the boring cavity, the fresh concrete undergoes alteration with bonds gradually forming. Such bonds may be:

- reversible: the term thixotropic behavior is employed here;
- or irreversible: introduced here is the term rheological loss, which in practical terms is reflected by a loss of workability.

Given the rheological characteristics of this concrete material, the speed of such an alteration may vary. A number of precautions must therefore be taken depending on the on-site pile installation time. This time is among the factors leading to the jamming of a reinforcement cage during its placement in the concrete. The key at this point is to ensure continuous concreting over a shortened period and compress the gap between the end of concreting and the placement of a reinforcement cage.

As per the concrete mix design and under the recommended implementation conditions for concrete, the time (of both concreting and waiting before reinforcement cage placement) and, hence, the thixotropic behavior of concrete may have a deleterious effect.

The structural evaluation protocol applied to concrete at rest incorporates:

- a rheometer test describing the evolution in concrete yield stress over time,
- a simple site test (Abrams cone slump) describing the evolution in concrete workability over time.

A. *The ICAR rheometer test*

The ICAR rheometer (Fig. 3), developed at the University of Texas, displays the advantages of being portable, simple and easy to use, and affordable [1]. This device comprises a lattice-like rotating tool for immersion into the concrete at a preset controlled rotational speed. Its operating principle is analogous to that of a coaxial cylinder rheometer.

This rheometer may be used to plot concrete flow curves, measure the material's static yield point or even characterize its thixotropy according to a procedure specified in its entirety by Koehler (2004).

The rheological behavior of fresh concrete has been described in this study by introducing four parameters:

- yield stress τ_0 and plastic viscosity μ_p. The protocol employed for this evaluation step consists of applying a decreasing shear rate ramp (from 0.5 to 0.05 rps) to the concrete, with the rheometer then outputting the flow curve (change in concrete yield stress vs. imposed shear rate). The dynamic yield stress and viscosity values can both be deduced from this curve.
- a thixotropy index A_{thix} and flocculation characteristic time T. At the jobsite, following a given resting time (allocated between concrete injection into the boring cavity and placement of the reinforcement cage), the concrete becomes sheared by the step of reinforcement cage installation. The thixotropy of the concrete is evaluated according to Roussel's protocol [2], which offers the advantage of studying concrete behavior under shear for various resting times. From a practical standpoint, the protocol described in Figure 4 can be applied with various resting times (1, 5, 10, 15, 30, 40 and 60 minutes). The concrete pre-shear phase at 3.14 s^{-1} (much higher than the test value) removes the concrete shear history (in particular the one related to concrete placement in the container), thus raising the level of test repeatability. The constant shear rate threshold at 0.414 rps (2.6 s^{-1}) is applied for a long enough time to reach equilibrium. The concrete temperature, test temperature and concrete slump at each measurement are all closely monitored.

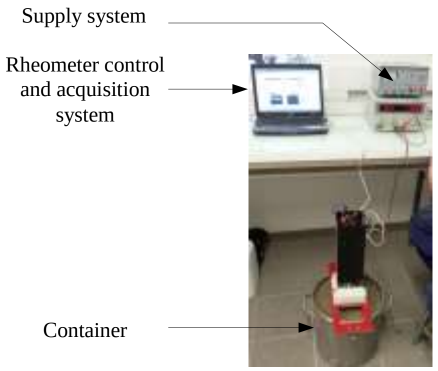


Figure 3. ICAR rheometer test set-up

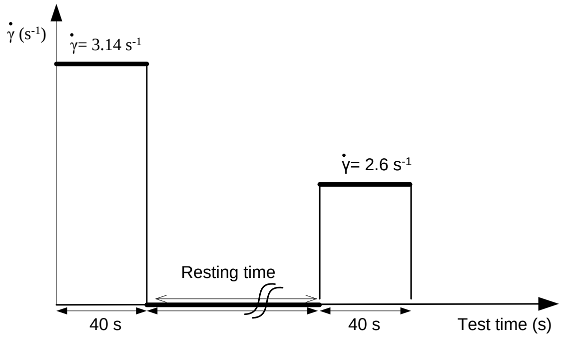


Figure 4. Assessment of thixotropy according to Roussel (2006)

The rheological properties of concrete evolve with the amount of resting time. The evolution of shear stress vs. time at rest (Fig. 5) indicates that over time, more energy is required to break the bonds between the various particles [3]. In applying a constant shear rate (2.6 s-1) to the concrete, the material loses its structure. Its shear stress then drops from a maximum value to an equilibrium value. As the time at rest lengthens, the maximum shear stress of the material rises. Moreover, the shear stress at equilibrium remains roughly the same regardless of the time at rest. The limited observed increase is mainly due to irreversible phenomena (loss of slump) that occur with long periods of time spent at rest.

The evolution in maximum shear stress is characteristic of the kinetics of concrete structural build up. Roussel described this evolution by the following equation:

$$\tau_0 (t)=(1+\lambda)\,\tau_0=\tau_0+\tau_0 t/T=\tau_0+A_{thix}t \qquad (1)$$

This equation allows evaluating:

- the thixotropy index of the concrete Athix at 0.18 Pa/s,
- its flocculation characteristic time T (i.e. the time necessary for the yield stress value to move from τ_0 to $2\tau_0$) at 20 min.

It can thus be considered that breaking the bonds between concrete components becomes difficult beyond 20 minutes.

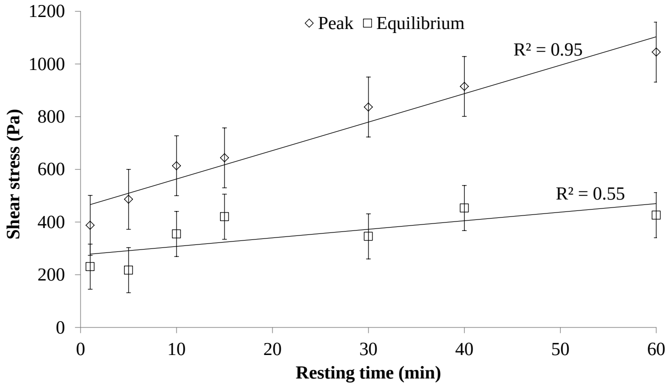


Figure 5. Evaluation of concrete structural buildup at rest

B. *Workability test*

The workability test set-up is the same as that prescribed in the NF EN 12350-2 Standard.

The results of Abrams cone slump measurements performed for various amounts of time at rest (1, 5, 10, 15, 30, 40, 60 and 90 minutes) reflect the true concrete workability prior to the actual on-site insertion of the reinforcement cage. For each measurement, the concrete is left at rest inside the Abrams cone for these specific time periods (Fig. 6), with recordings also kept of the concrete temperature (22.4° ± 1.1°C) and ambient temperature (20.0 ± 1.3°C).

The concrete retains its workability over the 18-22 cm interval for approx. 45 minutes (Fig. 7). A 60-minute study range (Fig. 5) was selected in order to focus exclusively on the thixotropic behavior of the concrete. Beyond this period, a rheological loss (i.e. loss of slump) occurs, which is indicative of concrete aging. Although aging also impedes penetration of the reinforcements, it does encompass a number of phenomena difficult to isolate.

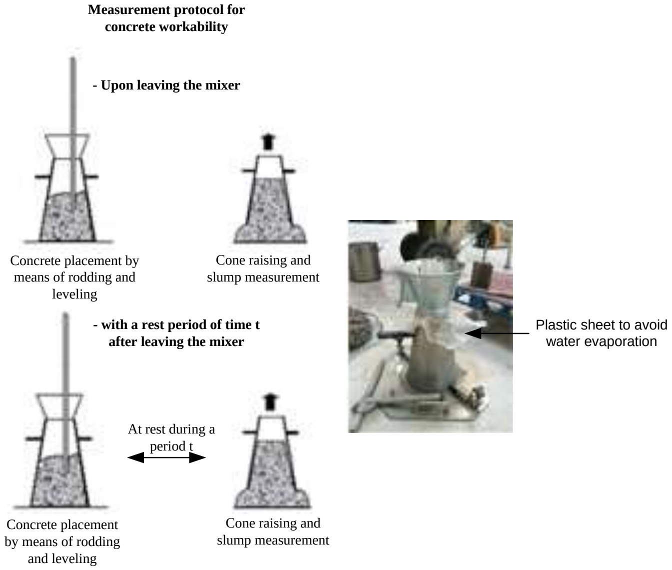


Figure 6. Measurement protocol for concrete workability

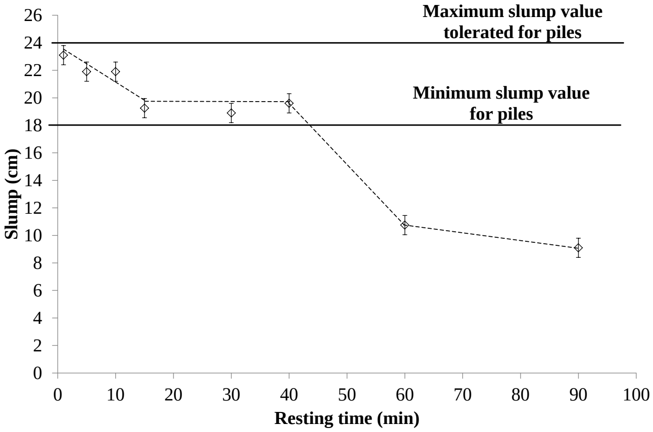


Figure 7. Study of continued concrete workability vs. time at rest

IV. Reinforcement cage penetration

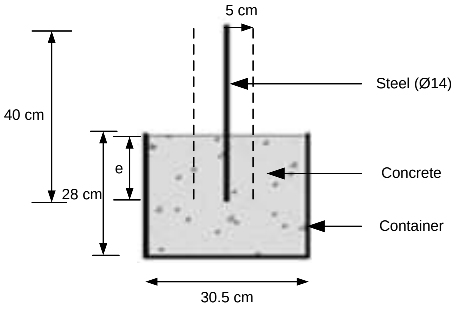
Given the phenomenon of reinforcement jamming during on-site placement, this part of the article will be devoted to studying the effect of concrete structural buildup while at rest on the capacity of the reinforcements to be subsequently introduced. An initial preliminary study was conducted using simple reinforcement (rods) in order to assess test protocol feasibility; the same study was then repeated with a reinforcement cage more representative of actual site conditions.

A. *Case of rod reinforcement*

- Test set-up: Fully described in Figure 8. The rod introduced has a 14-mm diameter and 40-cm length.
- Measurement protocol: we conducted penetration measurements for the rod under its own weight at various resting times in the middle of a cylindrical tank filled with concrete (Fig. 8).

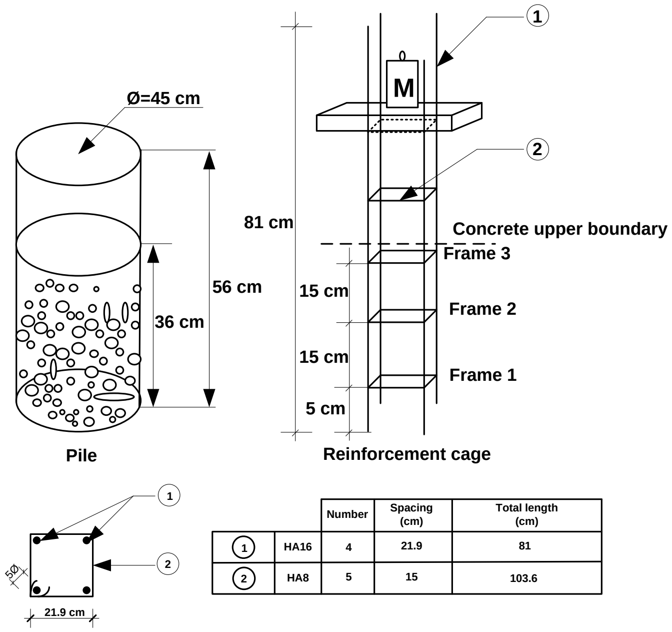
The rod penetration measurements in fresh concrete reveal a decrease in penetration with greater time at rest (Fig. 10). This reduction is a direct consequence of both the concrete structural buildup while at rest and the steel-concrete friction.

This preliminary study shows overall test feasibility. A series of penetration measurements were then carried out on a reinforcement cage in fresh concrete.



e: penetration length of the steel bar at the center of the container

Figure 8. Penetration measurement set-up for simple reinforcement in fresh concrete



		Number	Spacing (cm)	Total length (cm)
①	HA16	4	21.9	81
②	HA8	5	15	103.6

Figure 9. Penetration measurement set-up for a reinforcement cage in fresh concrete

B. *Case of a reinforcement cage*

- Test set-up: shown in Figure 9. The test is carried out on a prototype, 45-cm diameter pile with a 7-cm coating, which fully complies with the recommendations set forth in foundations standard. The concrete reaches a height of 36 cm in the tank. Moreover, masses are available for applying loads on the cage and a vibrating needle is also on hand for the concrete.
- Measurement protocol: the concrete is left at rest in a tank; then, cage penetration values under various loads (from 7.9 to 32.9 kg, including dead weight of the cage) are recorded. Lastly, the cage penetration rate is measured over the remaining length of the tank while vibrations are being applied at the top.

C. *Evaluation of reinforcement penetration capacity in fresh concrete*

The measurements of cage penetration into fresh concrete show a drop in penetration with increased time at rest. Whether for a steel rod or reinforcement cage, this logarithmic-type decrease occurs in two phases (Fig. 10):

- Part (a) of the curve corresponds to a gradual structural buildup of the concrete. The reinforcement penetration capacity, defined herein as the ratio of reinforcement penetration into the concrete at rest for time t to the penetration for a time at rest t0=1 min set as the reference value, declines from 100% to 50% after a 15 to 25-min interval for all configurations examined (rod, reinforcement cage and applied load).
- Part (b) corresponds to the period extending beyond the flocculation characteristic time of concrete. At this point, the cage penetration capacity dips from 50% to 30% (to 40% in the case of the rod) after 1 hour; this change in capacity is very small due to the high level of prior concrete structural buildup.

Studying the influence of time at rest on reinforcement penetration measurements in fresh concrete must also address the detrimental aspect of a frame compared to a rod. In performing the reinforcement cage penetration test for various loads, it was in fact determined that at a given point in time all 4 longitudinal reinforcements (i.e. rods) were penetrating until reaching frame 1, which in turn did not penetrate into the concrete (Fig. 11). For a given frame, the surface area of reinforcements in contact with the concrete is expanded, hence raising the level of concrete/reinforcement friction. Moreover, once frame 1 is embedded into the concrete, the other frames follow without any difficulty by inputting the load and then applying the vibration. A measurement set-up featuring just a single frame and guides can thus be envisioned.

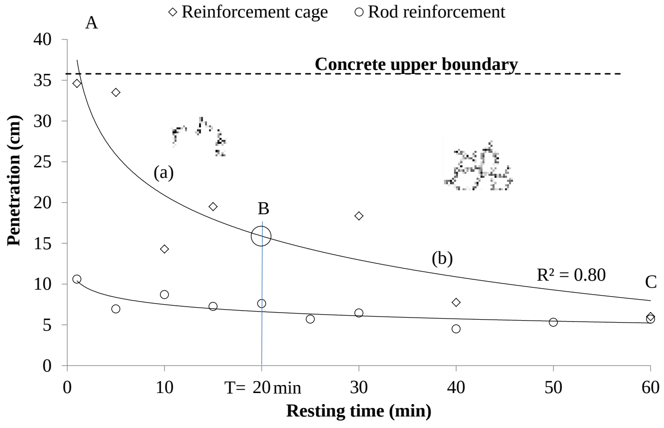


Figure 10. Cage penetration progress vs. time at rest under a 27.9-kg load

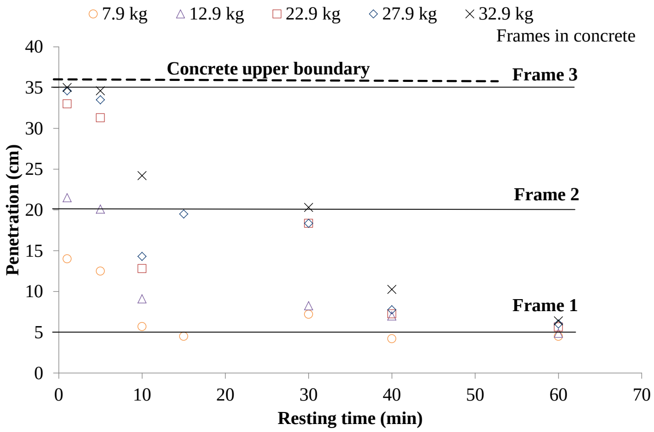


Figure 11. Evolution in reinforcement cage penetration in fresh concrete vs. resting time

D. *Concrete rheology and reinforcement penetration in fresh concrete*

This section is intended to establish a correlation between reinforcement penetration in fresh concrete and the parameters of concrete rheology.

The evolution in reinforcement cage penetration measurements with respect to concrete rheology properties is logarithmically related to the evolution in penetration measurements vs. time at rest (Fig. 12).

A stress threshold can therefore be found to exist (at approx. 850 Pa), from which point the concrete shear stress increases (from 850 Pa to 1 050 Pa after 60 minutes), while penetration only varies minimally (by roughly a cm). The existence of such a point presumes that beyond this stress level, the reinforcement cage jamming phenomenon is readily observed, in which case vibration would be required.

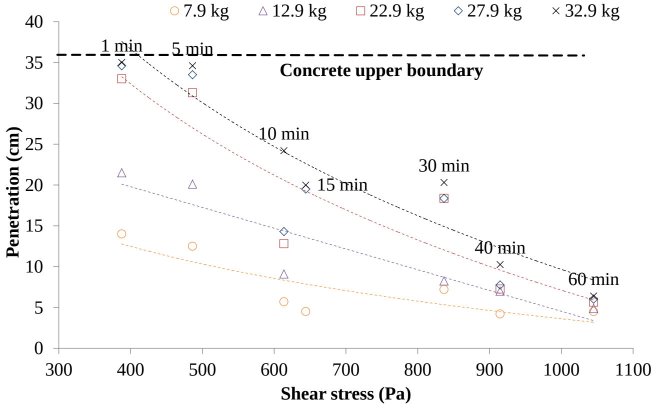


Figure 12. Evolution in reinforcement cage penetration vs. concrete rheology

V. Conclusion and outlook

This research has made it possible to study the effect of resting time on both concrete rheology and the capacity of reinforcements to penetrate the concrete. It has also demonstrated that the structural buildup kinetics of concrete at rest exert an influence on the capacities of reinforcements to become embedded. Moreover, the study conducted on changes in reinforcement penetration measurements vs. concrete yield stress has provided some definite benefits. It is expected to allow predicting, for this particular concrete mix design, reinforcement cage penetration as a function of: cage dimensions, applied load, and the duration of concrete resting time. Given the various observations and conclusions drawn from this study, protocols may be improved and tests conducted on prototype piles in order to consolidate and refine the penetration prediction model.

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