TEST METHOD USING PRESSURE FILTRATION CELL TO EVALUATE BLEED IN TREMIE CONCRETE

Thomas Holder, Soletanche Bachy, France, +33601070976, thomas.holder@soletanche-bachy.com
Christophe Justino, Soletanche Bachy, France, +33607227439, christophe.Justino@soletanche-bachy.com
Philippe Gotteland, FNTP, France, +33786176890, gottelandp@fntp.fr

ABSTRACT

Extensive bleeding of fresh concrete has been now clearly identified as a potential root cause for imperfection in deep foundation concrete elements. This paper deals with a new and quick test method to estimate the overall bleeding of a concrete. Its development has followed the understanding of the 3 phases of bleeding: induction period, constant bleed rate period and the final consolidation. The apparatus used for these tests is the ISO 10414-1 (API13B) pressure filtration cell, commonly available on foundation jobsite. This article presents the scientific approach and the experimental study that set the parameters (time and pressure, 3min15s 100 kPa/14.5 psi) of the test to predict the overall bleeding. The precision of the test has been established with an experiment that involved 7 operators for three concretes (with three level of bleeding). This experiment included a comparative study with the concrete filtration test under CIA Z17-2012. The new test can be used to determine the filter loss of a concrete as an alternative. Field tests were made on several French worksite to complete the laboratory studies. The test will be part of the French standards within 2021.

Keywords: Tremie concrete, fresh properties, bleed, filer press, concrete test standard, consolidation

INTRODUCTION

Uncontrolled bleeding of fresh concrete has been now clearly identified as a potential root cause for imperfection in deep foundation concrete elements. In order to limit the risk of anomalies created by subsequent bleed water preferential pathway, bleeding should be controlled.

EFFC/DFI Guide to Tremie Concrete for deep foundation (Tremie Guide) presents small scale testing and under pressure test to evaluate concrete performance for resistance to bleeding.

Research work by Massousi and al (2017) identified three important stages to describe bleeding of fresh concrete with the importance of qualifying the induction period (just prior bleed initiates) from the constant bleed rate period and the final consolidation phase where the overall bleeding has been established.

Induction period and constant bleed rate can be established with a small-scale testing (static bleed test), while under pressure filtration test could assess the consolidation phase, with a lower height of sample tested compared to CIA Z17-2012 procedure.

In 2019, FNTP (Fédération National des Travaux Publics) founded a comparative study of static bleed (XP 18-468) test with concrete filtration test under CIA Z17-2012 and an alternative procedure using ISO 10414-1 (API13B) pressure filtration cell.

This paper presents results obtained from a comparative study of bleed testing procedure on four different tremie concrete mix design with different bleed resistance ~~responses~~ levels: two concrete mixes conformed to the Tremie Guide section five, table 2 (recommendations for testing tremie concrete) and two additional mixes presenting higher filtration value and initial bleed rate. Comparison between filtration test and static bleed test from this study, is used to establish a new test procedure to predict the total bleeding of the concrete. This new test procedure has been used for a Precision and Bias study involving six different partners (five contractors and one concrete testing laboratory) to establish the repeatability of the two different filtration test method. The alternative pressure filtration method that will be applied in an experimental French standard. Finally, this paper presents a field-test study performed on 8 sites to compare the two filtration tests.

EXPERIMENTAL INVESTIGATION

Material and mix designs

A cement type CEM III/A (NF EN 197-1) was used with a Blaine of fineness 4150 cm²/g. Crushed limestone aggregates were used. The sand has a fineness modulus of 2.95, a water absorption of 0.57 % and a specific gravity of 2.66. The coarse aggregate with a nominal maximum size of 20 mm has a specific gravity of 2.66 and a water absorption of 0.77%. A fine siliceous river sand has been used to adjust the particle size distribution. It has a water absorption of 0.20 % and a specific gravity of 2.55. The superplasticizer used is the typical product employed for concrete for deep foundations (extended time retention). A retarder was used to ensure all concrete mixes have a workability retention of at least six hours.

Four mixes were developed for this study, the mix designs are presented in Table 1. The concrete C1 is a typical mix used for deep foundations in France. The concrete C2 is the same mix design with an increased retarder dosage. The concrete C3 is derived from C1, with same cement proportion and similar aggregate distribution but with higher effective water dosage. C1, C2 and C3 are complying with Annex D of the EN 206:2013 and Tremie Guide recommendation whereas mix C4 is not in compliance due to the cement quantity lower than minimum specified. The particle size distribution of the latter is significantly different.

The superplasticizer and the retarder have been adjusted for each concrete to target an initial Flow (EN 12350-5) of 630-660 mm ($24^{3/4}$ – 26 in.), in the higher range of the specified consistency, and a minimum slump value of 160 mm ($6^{1/2}$ in.) at 6 hours after initial mixing.

Table 1: Concrete mix design

Constituents	C1	C2	C3	C4
Cement, kg/m^3	385	385	385	330
Fine sand, kg/m^3	190	190	195	-
Sand, kg/m^3	690	690	680	800
Coarse aggregate, kg/m^3	930	930	915	1040
Superplasticizer, %$_{\text{w of cement}}$	1.10%	1.15%	0.40%	0.45%
Retarder, %$_{\text{w of cement}}$	0.20%	0.50%	0.40%	0.40%
Effective water, kg/m^3	168	168	188	181,5
Water/Cement ratio, -	0.44	0.44	0.49	0.55
Total fines at 125 µm, kg/m^3	530	530	528	496
Coarse aggregate / sands ratio, -	1.06	1.06	1.05	1.30

Methods

The consistency of the concrete (Flow, Slump and Viscosity) was followed for a minimum of 6 hours.
Note: Viscosity measured according to NF XP P18-469, inverted slump cone test.

The static bleed (NF XP P18-468) tests have been started between 30 and 45 minutes after mixing time. Measurements were made until the end of bleeding. The setting time of the concrete was estimated by recording the temperature evolution of a 15 L sample placed inside an insulated box. Setting time is estimated here as the time when the temperature increases of more than 0.5°C by 60 min.

The alternative filtration tests using the ISO 10414-1 (API13B) pressure filtration cell was used at three overhead pressure levels: 100, 200, and 300 kPa (14.5 ; 29.0 and 43.5 psi). The procedure CIA Z17-2012 was used at the overhead pressure of 500 kPa (72.5 psi). For each test, the measurement was followed until 15 minutes. The mass of the filtrate was recorded in real time by a scale and a camera. Each concrete was tested three times and the tests were launched between 20 and 45 minutes after the mixing time (two times for a first batch and one time for a second batch).

RESULTS AND DISCUSSION

Table 2 summarizes the consistency of the concretes and the retention during the time. The estimated setting time of each concrete is given. Fig. 1 shows the evolution of the flow of the concrete during the time. The four concretes present a suitable behaviour for tremie concreting. The flow of the concretes C1 and C2 is still in the target value (600±50 mm / $23^{1/2}$±2 in) for 6 hours, 4 hours for the concretes C3 and C4. The flow of concrete C1 and C2 remains in the initial consistency target value for 6 hours while it remains for 4h with concrete C3 and C4. All four concrete are compliant with the specified retention time of 6 hour with a slump value above 160 mm ($6^{1/4}$in). The concrete C4, with the higher coarse / sand aggregate ratio, is more subject to blockage during the viscosity test.

Table 2: Properties of the concrete measured for the consistency, density, and the setting time

Mix		*C1*	*C2*	*C3*	*C4*
Flow, mm	*30 min*	660	640	640	650
	1 hour	640	630	610	650
	2 hours	640	620	620	590
	4 hours	620	600	550	560
	6 hours	570	600	510	530
	8 hours	520	510	-	-
Viscosity, s	*30 min*	2.9	2.6	1.9	4.8
	2 hours	5.8	3.6	3.0	5.8
Slump, mm	*6 hours*	-	210	170	170
	8 hours	195	195	-	-
Density, kg/m³ (yield)	-	2397 (0.99)	2409 (0.99)	2346 (1.01)	2360 (1.00)
Setting time, hours		22.6	35.2	19.3	19.5

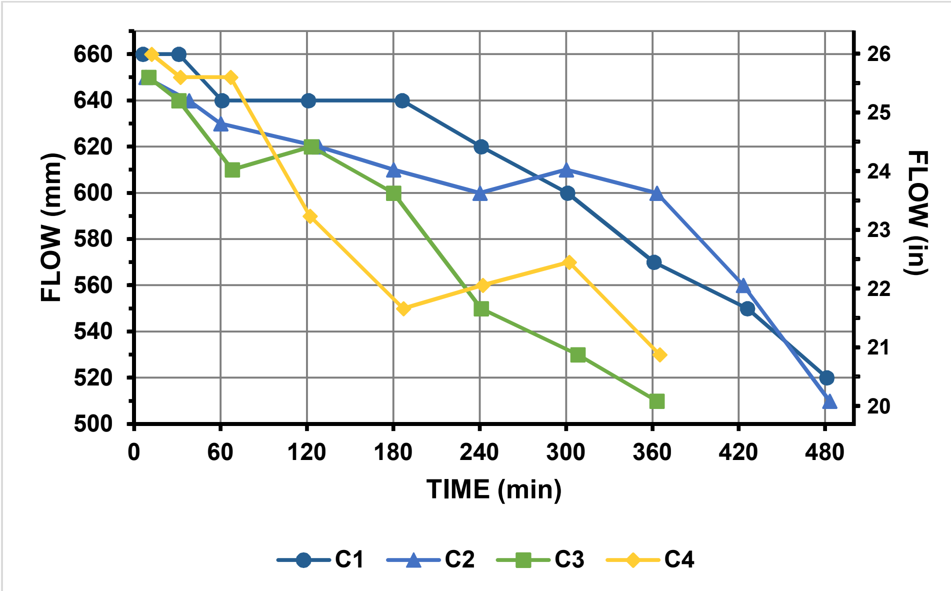


Fig. 1: Evolution of the flow of the concrete tested

Table 3 summarizes the results of the bleeding test and filtration tests according to the CIA Z17-2012 procedure. The fig. 2 shows the bleeding water collected over the time for each concrete. The mix C1 and C2 present an induction period of 60 to 90 minutes after casting of the sample. Bleed water can be measured until concrete reach its setting time. C1 has a continuous bleeding rate during the whole test. From the initial bleeding until 10 hours, C2 is similar to C1 then the bleeding rate increased. C3 and C4 have an induction period lower than 30 minutes and initial bleed rate superior than 0.100 ml/min (Tremie Guide recommendation). For these two mixes, the bleeding of water stops before initial set of the concrete. For the concrete C4, the initial and the maximum bleed rate (calculated for 2 hours) are the same. The filtration test results show that C1 and C2 are suitable for tremie concrete. C3 and C4 exceed the limit of 22 ml (Tremie Guide recommendation).

Mixes C3 and C4 are not considered as representatives of a normal deep foundation concrete but help to evaluate the new test procedure for non-compliant concrete. The C2 mix shows that a same composition can have a long to very long bleeding period linked to retarding. At the end of bleeding tests and before the setting time the bleeding speed of this concrete was less than 0.015 ml/min. It is possible to estimate that the concrete had reach the maximal consolidation.

Note 1: measurements are made by weighing the mass of collected water (bleeding or filtrate), density of water taken at 1.00.
Note 2: 1 mm/m = 0,13 in/ft

Table 3: Results of the bleeding test and filtration under the CIA Z17-2012, [1] Total bleeding as defined in the standard NF XP P18-468, [2] Total bleeding divided by the effective water in the sample tested.

	Mix	C1	C2	C3	C4
Bleeding test	Initial bleed rate, *ml/min*	0.028	0.031	0.211	0,434
	Maximum bleed rate for 2 hours, *ml/min* (age of the concrete)	0.055 *(from 4,5 to 6,5 hr)*	0.099 *(from 10 to 12 hr)*	0.239 *(from 5 to 7 hr)*	*Initial bleed rate*
	Total bleed water collected, *ml*	42.7	92.8	176.7	171.9
	Height of total bleed[1], *mm/m*	3.4	7.7	14.2	14.2
	Proportion of effective water collected[2]	2.0 %	4.6 %	7.6 %	7.8 %
	End of the bleeding before the setting time	No	No	Yes (60 minutes before)	Yes (6 hours before)
Filtrate collected at 5 minutes, average, ml ***Individual results, ml***		9,2 *10.5 | 8.0 | 9.2*	10.7 *12.1 | 10.1 | 9.8*	24.0 *25.0 | 21.9 | 25.1*	25.7 *26.6 | 24.0 | 26.6*
Suitability for tremie concrete		*Yes*	*Yes*	*No*	*No*

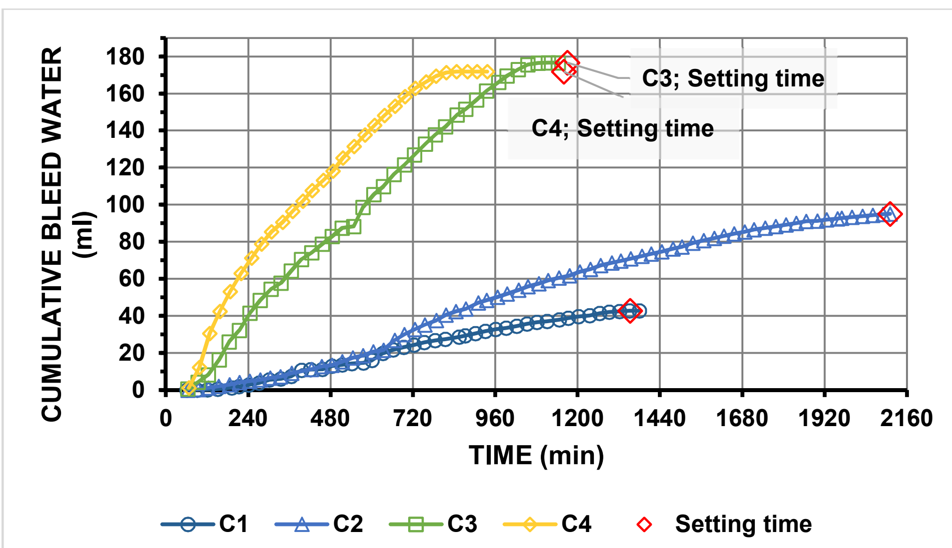
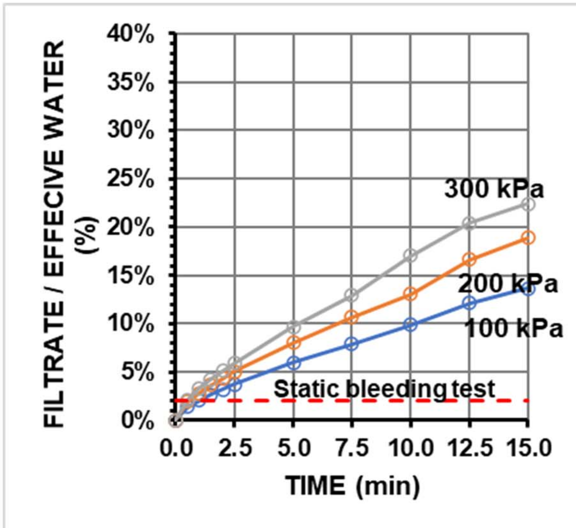
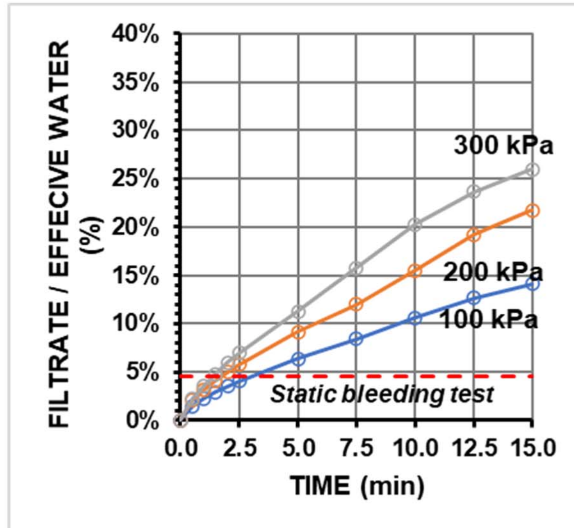


Fig. 2: Relation of the cumulated bleed water collected with time

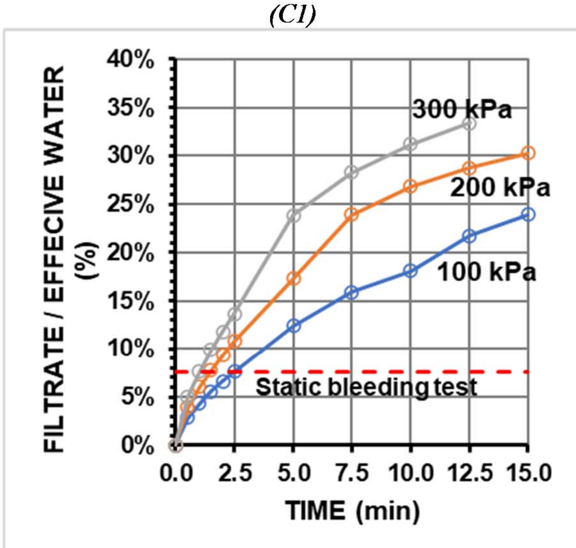
The Fig.3 shows the evolution of the filtrate at the different overhead pressure for the API13B filtration cell for each concrete. The results are the average of three tests. The filtrate is expressed as percentage of the effective water. The dot line highlights the proportion of the effective water measured by the static bleeding test (Table 3). For an overhead pressure of 300 kPa (43.5 psi), the tests were stopped before 15 min for concretes C3 and C4 as no water was passing any more. These results show that the static bleeding test measures can be reached by the filtration cell test before 5 minutes.



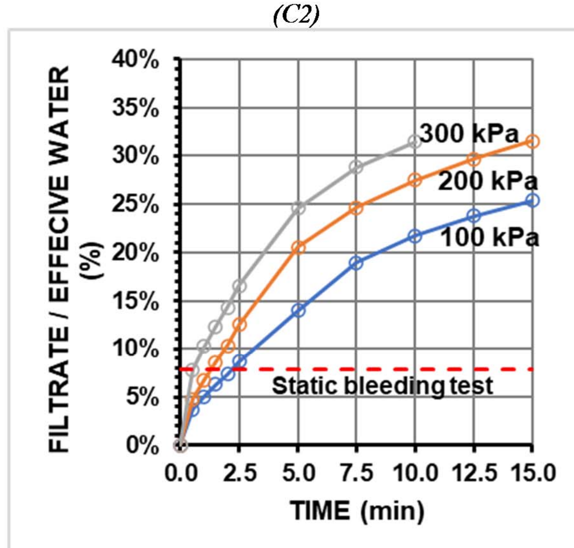
(C1)



(C2)



(C3)



(C4)

Fig. 3: Evolution of the filtrate with time, expressed as percentage of the effective water in the sample tested, for each overhead pressure and comparison to the result of the static bleed test

The first 3 lines of the Table 4 show the time to reach the static bleeding test result for each overhead pressure and for each concrete. The longest times to reach the static bleeding test result are observed for the mix C2. The mix C2 showed in the meantime a compliant bleeding rate and a final bleeding reached before the setting time for a high retardation. C2 is then proposed as the reference mix. The time calculated to reach the total bleeding of C2 is used as reference with a small margin. The maximal bleeding, if no setting time occurred, is then estimated with the filtration test at 03:15 for an overhead pressure of 100 kPa (14,5 psi); 02:00 for 200 kPa (29 psi) and 01:30 for 300 kPa (43,5 psi). The consolidation of each concrete for each overhead pressure are presented in the 3 last lines of Table 4. For C3 and C4 total consolidation is higher than the total height of bleeding. The time selected give a conservative estimation of the total bleeding for these two concretes. For C1, the consolidation with the filtration is higher than the bleeding test due to the setting of the concrete before the total bleeding.

The API13B filtration cell can be used to estimate the maximum bleeding height of the concrete at the static bleed test. The 100 kPa and 3:15 is selected as it is the more appropriate for a test development.

Table 4: Results of the tests with the API13B filtration cell, comparison to total bleeding and analysis with the reference time of C2

Mix		C1	C2	C3	C4
Time to reach the static bleeding test result, % of effective water	100 kPa	00:56	03:04	02:29	02:09
	200 kPa	00:33	01:47	01:27	01:17
	300 kPa	00:28	01:22	01:00	00:30
Height of bleeding at the time selected, *mm/m*	03:15 - 100 kPa	7.4	8.0	17.0	18,7
	02:00 - 200 kPa	7.3	8.3	17.5	19.5
	01:30 - 300 kPa	7.1	8.1	18.6	26.9
Height of bleeding at the end of the static bleeding test		*3.4*	7.7	14.2	14.2

NEW TEST PROCEDURE BASED ON ISO 10414-1/API 13B, PRECISION AND BIAS

New test procedure

API 13B/ISO 10414-1 filtration cell study results confirmed the potential for tremie concrete bleed evaluation with a testing apparatus already available on site. For the purpose of developing a new experimental standard in France, the following procedure is proposed:

1) remove any excess moisture in the filtration cell
2) record the mass of the filtration cell, m_1, in g
3) fill the filtration cell in one layer, until 10-5 mm to the top of the filtration cell. Compact the concrete with 5 strokes with the tamping rod.
4) Record the mass of the filtration cell and the concrete, m_2, in g
5) Start the filtration test and start the stopwatch as soon as the pressure starts to rise, a pressure of 100±10 kPa should be obtained withing 5 to 10s.
6) Collect the filtrated water from 15s to 03:30, maintain the pressure 100±5 kPa (14.5±0.75 psi) during the test
7) Weight the filtrated water at ± 0,1g, m_4 (m_3 is the weight of the measuring flask)
8) Calculate the Consolidation of each test:

$$C_{Mi} = \frac{m_4 - m_3}{V_{concrete}}$$

Where, $V_{concrete} = \frac{m_2 - m_1}{Density\ of\ the\ concrete}$

Expressed C_{Mi} , the consolidation of the concrete, in mm/m.

The test should be repeated two times with the same sample of concrete. If the filtrate $(m_4 - m_3)$ of each test differ of max (0.7 g ; 15 %), a new test should be performed.

The result is $C_M = \frac{C_{M1} - C_{M2}}{2}$

Note: a specific manometer with a 250 kPa (35 psi) scale must be used to perform the test with the accuracy measured during the precision and bias study. Density of concrete is expressed in kg/m^3

Methods for the precision and bias study

Six different partners (five contractors and one concrete testing laboratory), seven operators in total have been invited to perform a precision study. The tests have been made for three concretes with different level of consolidation. The materials used for the concrete are the same as the previous study. The mix designs where slightly modified to have two different concretes with high filtration resistance and low bleeding (concretes C5 and C6) and one concrete with high level of bleeding (C7). For each batch, the flow, the viscosity and the density of the concrete have been tested at 20 minutes and the volume of the concrete have been distributed in 7 different buckets. Each operator used its own bucket to perform 2 filtration tests according to the procedure hereinbefore. Two filtration tests were as well performed according to the CIA Z17-2012 procedure. All tests have been made between 30 minutes and 75 minutes after the introduction of water in the mixer.

The precision data are analysed according to the ISO 5725-2.

Results of the precision and bias study

The Table 5 presents the results of flow, viscosity and density of the concretes.

Table 5: Synthesis of the properties of the concrete measured before the filtration tests

Mix		*C5*	*C6*	*C7*
Flow, mm	*Initial*	600	640	580
	20-30 min	650	620	520
Viscosity, s	*15min*	5.5	2.9	1.4
Temperature, °C	*15min*	20.1	19.3	18.6
Density, kg/m³ (yield)	-	2403 (0.99)	2409 (0.99)	2350 (0.99)

Figs 4, and 5 show the results of the new filtration test and the filtration test according to the CIA Z17-2012 procedure. The dot lines represent the average result for each concrete/test. The statistical analysis is given in the Table 6 for the new filtration test and the Table 7 the CIA test procedure. No outlier was detected by the Cochran and Grubbs tests. The standard deviation for reproducibility is linearly dependant. The final precision data are expressed linked to the value of the test "C_M" or "F" respectively for the new filtration test or the CIA procedure. In comparison to the average values, the precision data of the two tests are similar.

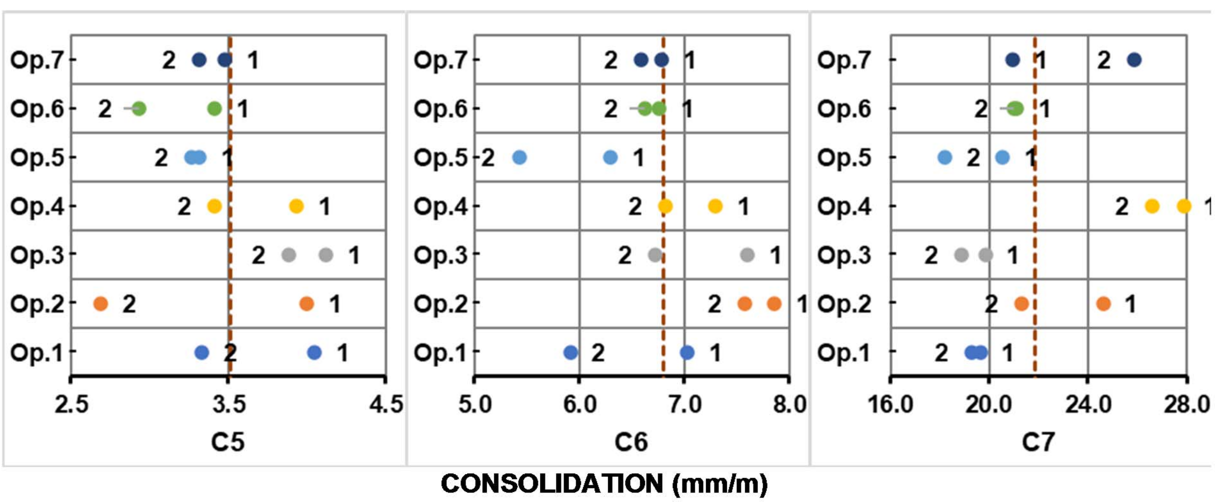


Fig. 4: Results for each operator for the new filtration test

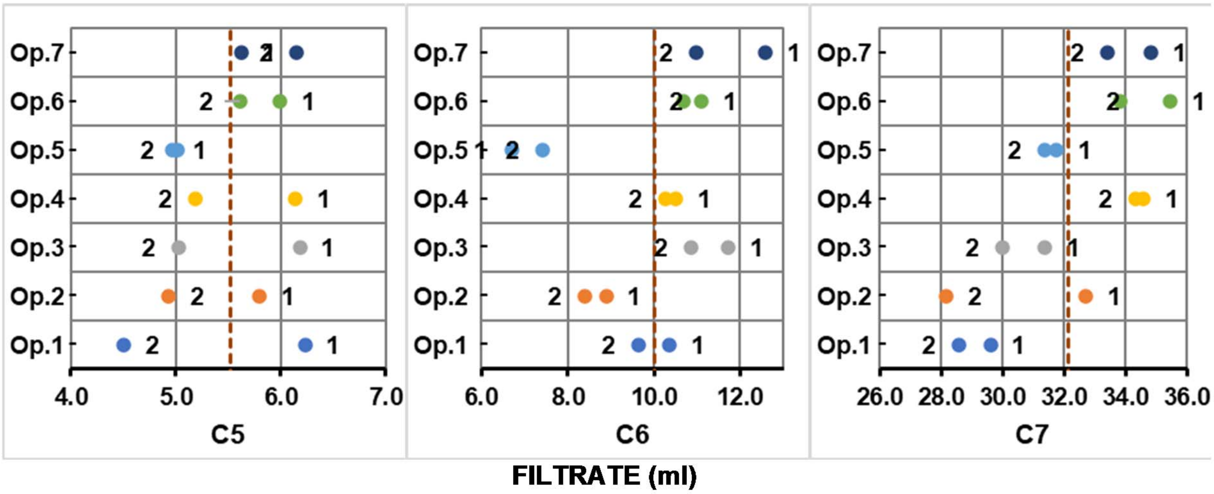


Fig. 5: Results for each operator for the CIA Z17-2012 test

Table 6: Precision data for the new filtration test

Mix	Average value (mm/m)	Repeatability conditions		Reproducibility conditions	
		S_r (mm/m)	r (mm/m)	S_R (mm/m)	R (mm/m)
C5	3.5	0.45	1.3	0.43	1.2
C6	6.8	0.48	1.3	0.68	1.9
C7	20.2	1.82	5.1	1.98	5.5
-	**3.5 to 20.2**	0.09 x C_M	0.25 x C_M	0.10 x C_M	0.28 x C_M

Table 7: Precision data for the CIA filtration procedure

Mix	Average value (ml)	Repeatability conditions		Reproducibility conditions	
		S_r (ml)	r (ml)	S_R (ml)	R (ml)
C5	5.5	0.68	1.9	0.57	1.6
C6	10.5	0.60	1.7	1.18	3.3
C7	32.1	1.43	4.0	2.46	6.9
-	**5.5 to 32.1**	0.03 x F +0.4	0.08 x F +1.4	0.07 x F + 0.3	0.20 x F +0.8

USE OF THE NEW TEST PROCEDURE ON SITE AND COMPARISON TO CIA Z17-2012

Field-test have been planned to validate the possibility to use this test on sites with deep foundation concretes. The field test has been used as well to perform a comparative study with the CIA Z17-2012 filtration procedure. 8 jobsites from 3 contractors were visited to perform the new test procedure. 4 to 6 different deliveries of concrete were tested. For each truck tested, a representative sample has been taken in accordance to EN 12 350-1 and kept in a sealed container between the tests, at least two tests were performed with the new filtration test and one filtration test according to CIA. The results are given in the Tables 8 and 9.

For all the sites, the values are consistent around the average. The fig. 6 shows the good relationship that can be found between the two filtration tests. The target of 22 ml specified by the tremie concrete guide for deep foundations could be linked to a maximum consolidation of 13 mm/m.

Table 8: Field test for the new filtration test, results in mm/m

Site	Average consolidation	Max. consolidation	Min. consolidation
Site 1	4.8	5.7	4.1
Site 2	6.4	7.0	5.9
Site 3: 1st visit	6.1	6.8	4.9
Site 3: 2nd visit	7.4	8.4	6.4
Site 4	7.6	8.1	7.0
Site 5	3.9	4.3	3.5
Site 6	5.4	6.0	5.0
Site 7	9.6	10.0	9.2
Site 8	9.7	10.9	8.4

Table 9: Field test for the CIA Z17-2012 procedure, results in ml

Site	Average filtrate	Max. filtrate	Min. filtrate
Site 1	9.0	11.2	7.7
Site 2	11.6	14.0	10.2
Site 3: 1st visit	8.4	8.6	8.0
Site 3: 2nd visit	10.3	12.0	9.0
Site 4	13.7	16.0	11.7
Site 5	5.5	6.2	4.6
Site 6	10.0	10.6	9.3
Site 7	15.6	17.3	15.1
Site 8	16.3	17.6	14.5

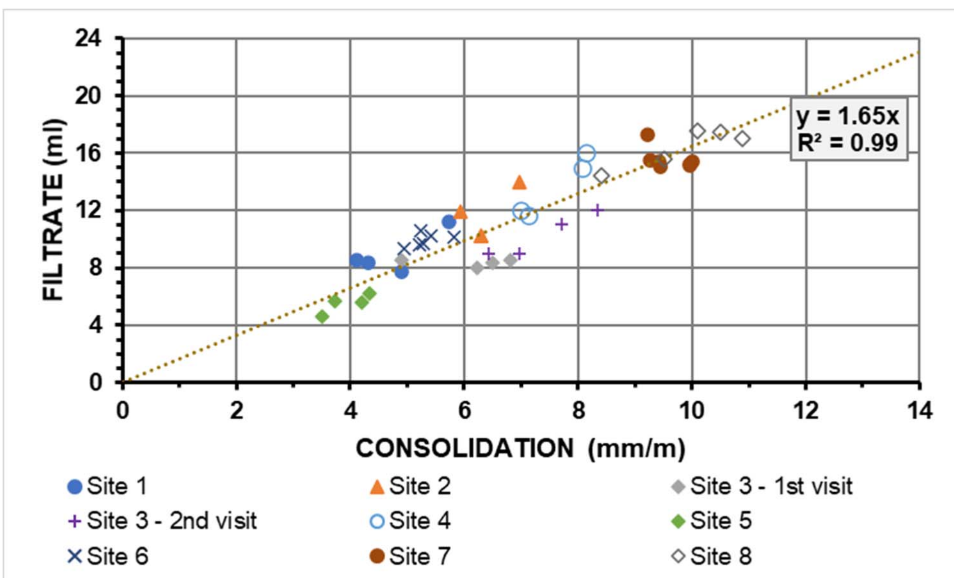


Fig. 6: Relationship between the new filtration test (consolidation) and the CIA filtration test

CONCLUSION

This paper presents a comparative study between the bleeding and the filtration behaviour of different concrete mixes. Two of the concretes tested conforms to the EFFC/DFI Guide to tremie concrete (consistency, bleed and filtrate). The API 13B/ISO 10414-1 filtration cell was used at different overhead pressure. The results show that the API 13B can be used to estimate the maximum consolidation of a concrete (or the maximum bleeding of a concrete). Based on the results a new filtration test procedure is presented with the API 13B filtration cell. The test is performed with an overhead pressure of 100 kPa for 03:15. The result (the consolidation of the concrete) is expressed in mm/m and can gives an estimation to the total bleeding of the concrete as defined in the NF XP P18-468. The precisions data of the new filtration test and the CIA Z17-2012 were established according to the standard ISO 5725-2. Both tests have similar precision in comparison to the average results. The field-test shows that the two filtration tests are well correlated. The use of the API 13B/ISO 10414-1 filtration cell for concrete can help to rationalize the testing equipment on site and will be be applied in an experimental French standard.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support of FNTP, the members of FNTP technical materials steering committee and all the participants for the bias and precision study (Soletanche Bachy International, Sigma Beton, Vinci Construction France, Botte Fondations, NGE Fondations, Franki Fondations).

REFERENCES

Massousi N, (2017). Ressuage des matériaux cimentaires : origine physique et changement d’échelle, Université Paris Est, NNT : 2017PESC1146.

EFFC/DFI Concrete task group, (2018). Guide to tremie concrete for deep foundations Second Edition

Z17, CIA (2012). Tremie concrete for deep foundations. Recommended Practice, Concrete Institute of Australia, Australia.