5th International RILEM Symposium on Self-Compacting Concrete
3-5 September 2007, Ghent, Belgium

EVALUATION OF GRAVITATIONAL FLOW TESTS WITH SCC IN PIPES AS A FORECAST FOR PUMPING PRESSURES

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Abstract

In construction, a large amount of SCC is pumped daily into a formwork without any fundamental knowledge of the flow characteristics. As a result, the pumping system is mostly not operated under optimal circumstances. At Ghent University, pumping tests are planned in order to evaluate hydraulics laws and rheological parameters during pipe flow. In order to prepare these tests, a gravitational flow test-setup has been developed for SCC.

The results of these tests, described in this paper, indicate a good agreement between rheological tests and the flow resistance of SCC in pipes, and show the validity of Poiseuille's law for laminar flow. The test results with the shortest pipe (3m) indicate that in this case second order effects, like entrance and exit effects have a substantial effect on the flow.

1. INTRODUCTION

When applying SCC in construction, different casting techniques are available. One of these techniques is pumping SCC into the formwork from the top or from the bottom. The pumping operations are mostly governed by the experience of the operator or by trial and error. There is mostly no fundamental understanding of the phenomena occurring during the flow of SCC in the pipes, and as a result, the system is not operated under optimal circumstances [1][2].

In order to better understand the flow of SCC in pipes, gravitational flow tests have been performed at Ghent University. By these tests, the validity of hydraulics laws in laminar regime can be verified, the rheological parameters obtained with rheometer tests can be compared and a preliminary forecast of the pressure losses at higher discharges can be elaborated.

2. TEST-SETUP

2.1 Gravitational flow test

The test setup consists of a vertical tube with a height of 2.3 m and an inner diameter of 300 mm, which can be closed at the bottom by means of a valve. Behind that valve, several steel pipes with an inner diameter of 105 mm and a length of 3 m can be connected. Tests have been performed with 1, 2, 3 and 4 pipes of each 3 m of length. At the end of the last pipe, the concrete flows out freely into a reservoir suspended to a rolling bridge. This suspension is equipped with a load cell, measuring the force executed by the weight of the concrete. Inside the upstream tube, a floating device is connected with a displacement sensor, measuring the height of the concrete inside the tube. Both the load cell and the displacement sensor register the data at least twice a second.

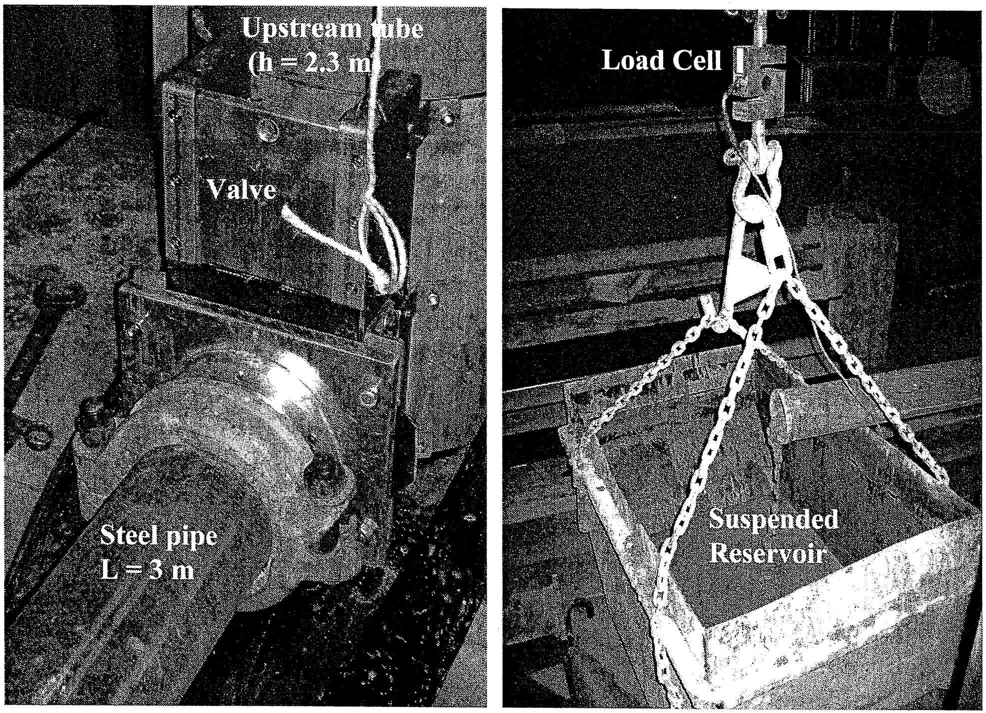

Figure 1: Left: the connection between the upstream tube and the steel pipe, equipped with a valve. Right: Load cell measuring the weight of SCC flowing into the suspended reservoir.

2.2 Rheometer

During a flow test, the rheological characteristics, after elimination of the thixotropy, have been determined with the Tattersall Mk-II rheometer [3][4].

3. MATERIALS

In total, 15 concrete mixes have been produced, of which the principal mixes are displayed in table 1. The main two parameters which have been tested are the length of the pipe and the type of SP. Both SP used are polycarboxylethers, of which SP 1 has longer workability retention and SP 2 is more efficient. For the tests with 3 m of pipe, one batch of 200 liter of SCC was sufficient. For tests with longer pipes: 6, 9 and 12 m, the total amount of SCC had to be produced in two consecutive batches. As a result, some small differences in workability have been observed between two consecutive batches. For each concrete, the density and sieve stability has been determined, together with the slump flow for each batch produced [5].

Table 1: Composition of principal mixes

	SCC 1	SCC 2	SCC 3
Gravel 8/16 (kg/m³)	434	459	434
Gravel 2/8 (kg/m³)	263	278	263
Sand 0/4 (kg/m³)	853	901	853
CEM I 52.5 N (kg/m³)	360	300	360
Limestone filler (kg/m³)	240	200	240
Water (l/m³)	165	165	165
SP-type	SP 1	SP 1	SP 2
W/P	0.275	0.330	0.275
Tested at	3, 6, 9, 12 m	6, 9, 12 m	3, 6 m

4. RESULTS

4.1 Testing procedure

Before starting a test, the pipes were not prepared with a water-cement mixture or chemicals [6]. As a result, the first time SCC was flowing through the pipes, it lost a lot of paste and the front of the concrete consisted purely out of stones. Once this plug of stones has flown out of the pipe, the valve was closed and the setup was ready for the first test. Approximately 30 min after the water-adding-time of the second batch of concrete, the first test was started. When the flow stopped at the end of the pipe, the test was finished and the SCC in the suspended reservoir was put in the upstream tube again. In this way, several tests have been conducted at 30, 60, 90, 120, 150, 180 and even 210 min after water-adding time, depending on the workability of the concrete at each moment. The pipes have not been cleaned between two tests with the same concrete. In this way, the presence of a plug of gravel when starting the flow only occurs before the test at 30 min.

4.2 Results

Values of discharge (Q) and upstream pressure (p) in time can be calculated from the data obtained with the load cell and the displacement sensor respectively. The flow of SCC at low discharges was rather discontinuous, resulting in large fluctuations when calculating the discharge. As a result, a mathematical curve fitting (eq.1) has been performed on the data of the measured volume in function of time.

$$V(t) = (a \cdot \tanh(b \cdot t) + c \cdot \tanh^2(d \cdot t)) \cdot e^{(-f \cdot t)} + g \cdot (1 - e^{(-K \cdot t^3)}) \cdot (1 - e^{(-h \cdot t)}) \qquad (1)$$

This formula has 2 terms: the first one is describing the rising part of the volume, which is extinguishing when time is increasing. The second term describes the final part of an s-curve, in order to obtain a discharge equal to 0 when the test stops. In total, it has 8 parameters which need to be determined. No attention should be paid to the physical meaning of these parameters, because the formula is only a mathematical aid to deal with the data properly. The derivative of equation 1 results in a formula giving the discharge in time at the end of the pipe. In fig. 2, the volume V and discharge Q are displayed in function of time.

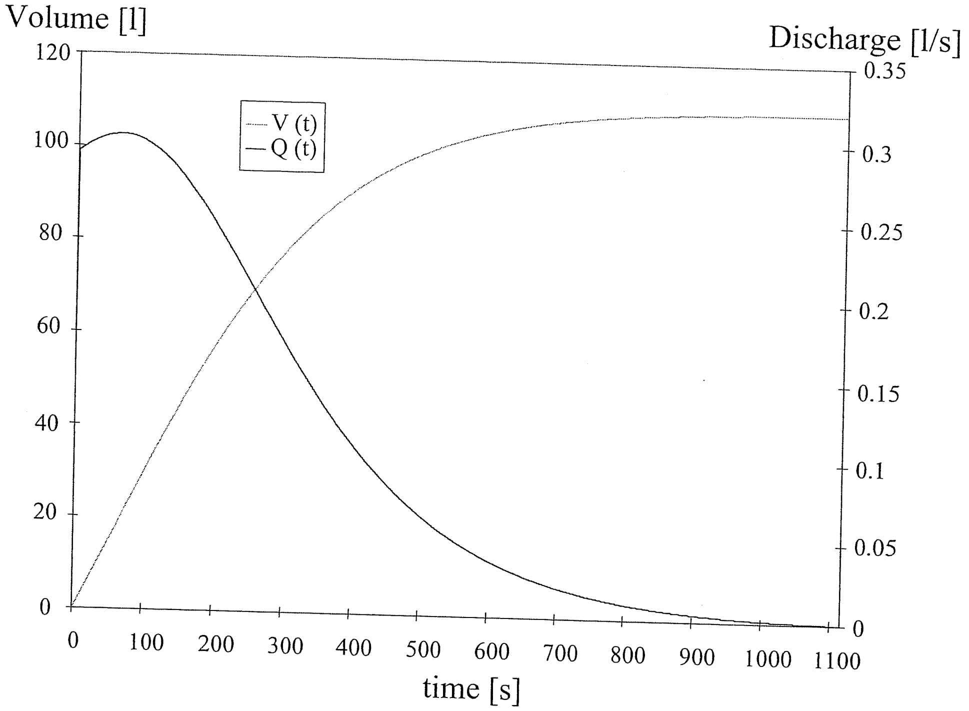

Figure 2: Mathematical approximation of the volume of the suspended reservoir and the discharge at the end of the pipe in function of time.

Remark that the curve for the discharge shows a peak in time. This means that in the beginning, the flow is accelerating, while the pressure in the upstream tube is decreasing continuously. This effect is mainly caused by the thixotropy of SCC when the flow has started. Thixotropy can be considered as eliminated when the curve Q(t) has passed the point of maximal deceleration, indicated by the inflection point of the curve. For the SCC in fig. 2, the inflection point is found at 254 s.

5. DISCUSSION

5.1 Length of the pipes

When comparing the test results of SCC 1 with a pipe length of 6 and 9m (named SCC1-6 and SCC 1-9), indicated in fig. 3, one can see that for each discharge, the ratio of the pressure fro SCC 1-6 to the pressure for SCC 1-9 is very close to 2/3. As a result, the pressure at a certain discharge is linearly dependent on the length of the pipe. This result is also valid when taking into account the results of SCC 1-12, keeping in mind that the rheometer tests indicate that the SCC 1-12 showed slightly more resistance compared to the SCC 1-6 and SCC 1-9, which have almost equal rheological properties. The rheometer tests also indicate that SCC 1-3 was more fluid compared to the others. As a result: the pressures for the test at 3m should be less than the half of the pressures at 6m. Fig. 3 indicates much higher values, which could be due to extra pressure losses caused by other effects occurring in the pipe (entrance, exit, ...), which gaining importance as the pipe is getting shorter.

The results in fig. 3 also indicate that the pressure is increasing linearly with the discharge. The non-linearity is the result of the shear thickening behaviour of the concrete [4].

From the results of SCC 1-6, SCC 1-9 and SCC 1-12, a linear dependency of the pressure on both the discharge and the length of the pipe has been obtained, with deviations caused by differences in rheological behaviour. These conclusions are also stated by Poiseuille's law for laminar flow of Newtonian liquids [7], meaning that the flow of SCC is occurring in laminar regime. The authors would like to remark that the obtained discharges are very low, which means that extrapolation to pumping tests is only valid if the flow remains laminar and no formation of slippage layers occurs [6].

For SCC 2, similar results have been obtained, but the interpretation is more complex, due to larger differences in rheological behaviour.

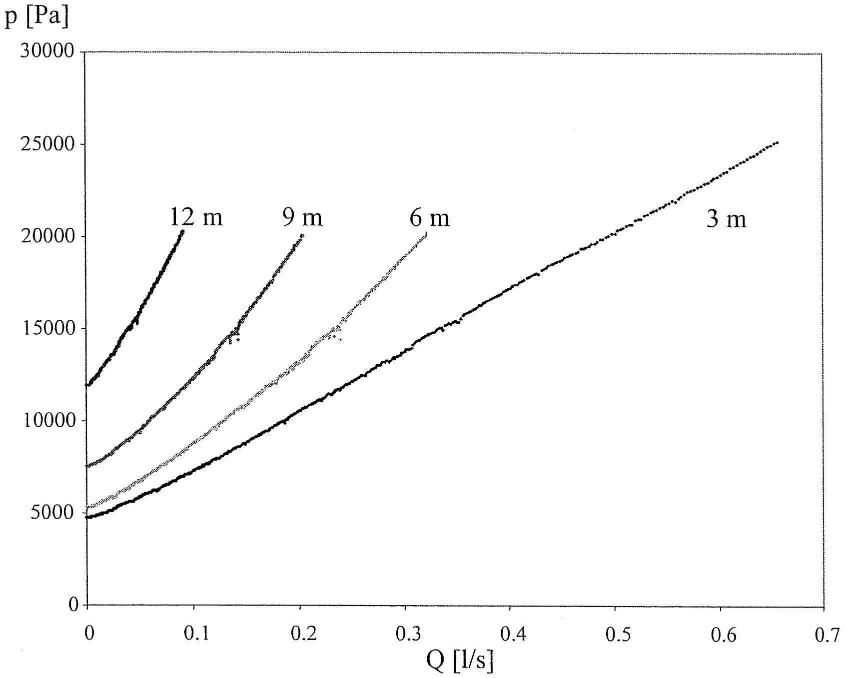

Figure 3: Pressure (p) vs. discharge (Q) for SCC 1-3; 1-6; 1-9 and 1-12, aged 60 min.

5.2 Flow tests compared with rheological parameters

The flow test-setup can be considered as a capillary rheometer, measuring the pressure loss over the pipe at a certain discharge. By means of equations 2 and 3, the data of p (or Δp) and Q can be transformed to shear stress and shear rate [8].

$$\tau = \frac{D \cdot \Delta p}{4L} \tag{2}$$

$$\dot{\gamma} = 3\left(\frac{8Q}{\pi D^3}\right) + \frac{D \cdot \Delta p}{4L} \cdot \frac{d(8Q/\pi D^3)}{d(D \cdot \Delta p/4L)} \tag{3}$$

Applying this transformation to the data of the flow tests, results in the same conclusion as in the previous section: For a short length of pipe, the shear stress at a certain shear rate is higher in case of the pipe, compared to the rheometer. The longer the pipe, the better the results of pipe tests and rheometer tests agree. Differences in rheological parameters, like the changes in workability loss caused by the application of a different kind of SP (SCC 1 compared to SCC 3) are also visible in p-Q data from the flow tests.

6. CONCLUSIONS

Gravitational flow tests have been carried out with pipes of 3, 6, 9 and 12m of length and different SCC-mixes. The purpose of these tests was to verify whether hydraulics laws are applicable. After the elimination of thixotropy, results of the tests indicate that:

- The pressure needed to obtain a certain discharge is linearly dependent on the length of the pipes.
- For a given length of the pipe, the pressure is varying linearly with the discharge
- Deviations from the above stated conclusions are caused by differences in rheological parameters and shear thickening respectively.
- Poiseuille's law for the pressure losses in a pipe in case of a Newtonian liquid gives the same conclusions, if the flow is laminar. As a result, the flow-tests have been performed in laminar regime.
- Tests with short pipes (3m) indicate that in this case secondary effects (entrance, exit, ...) cause extra resistance to flow.
- The results obtained with longer pipes (9, 12m) accord very well to the obtained rheological data with the Tattersall Mk-II rheometer.
- Extrapolation of these data can predict the needed pressure to pump SCC, with known rheological parameters, at a certain discharge, but only if the flow during the pumping remains laminar and no segregation of the concrete occurs in the pipes.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Fund for Scientific Research in Flanders (FWO) for the financial support of the project.

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