# DESIGN AND APPLICATION OF A NEW RHEOMETER FOR MEASURING THE PUMPABILITY OF FRESH CONCRETE ON SITE

M Greim*

** Schleibinger Geräte Teubert u. Greim GmbH, 84428 Buchbach, Germany*

**ABSTRACT**

Each individual ingredient of a concrete formula has an effect on the pumpability of the concrete. For example, admixtures and additions for reducing the water content and the proportion of cement may have a negative impact on the pumpability of the concrete. The new SLIPER measuring device (SLIding Pipe RhEometer), developed in cooperation with a concrete pump manufacturer, allows the user to quickly assess the pumping characteristics of concrete and other materials in the laboratory and on the construction site before they are used.

The SLIPER provides a vertical standing standard pipe which is filled with fresh concrete.
In the pipe there is a piston which is standing on the ground floor. Integrated into the top of the piston there is a pressure sensor. If the pipe is sliding downwards, the pressure in the pipe is measured. Also the speed of the pipe is recorded. The measurement data are sent wireless to a common smart phone. There the data are stored and displayed graphically. The properties of the fresh concrete are evaluated by the software App included. With this software the design and parameters for the pump application may be estimated. Therefore a computational model is used which calculates the expected pressure loss in the concrete pump. The system is portable, robust, battery driven and designed for the construction site.

## 1.0 Problem

Most of the modern concrete is pumped at the constructing site. The pumping height and distance may vary from several meters up to more then 600 meters at modern high rise buildings. The necessary pumping pressure strongly depends on the concrete mix design. Unfortunately there is no clear correlation between the common concrete flow tests like the slump flow or shock table test and the pumpability of fresh concrete. This is also true for more modern test like the L-box test, the J-ring or the V-funnel test. Even with the most modern concrete rheometers the predicting of the maximum pressure or pump volume per hour is not possible. The pumpability of fresh concrete is not only influenced by the rheological properties of the concrete itself but also by the interface zone between the concrete and the pipe. The flow properties of fresh concrete are also changing with the pumping pressure which may reach values up to 200 bar.

## 2.0 Objective

About 10 years ago Knut Kasten from the company Putzmeister, a German concrete pump manufacturer, started the development of a new device for measuring the pumpability of fresh concrete. Objective of this development was a simple, robust and portable instrument that simulates the conditions in a concrete pump as close as possible. Finally a new instrument called sliding pipe rheometer, SLIPER, was designed. This concept was proven theoretically [1, 2, 6] and practically in many real world applications. Since 2015 the SLIPER is also commercially available.

## 3.0 SLIPER

### 3.1 Design and Handling

In most concrete pump a piston is moving a certain volume of fresh concrete in a certain timed and pressure through a pipe. Figure 1 a and b shows the design of the SLIPER. In opposite to a concrete pump the piston is fixed and the pipe is moved. The pipe is filled with 6 liters of fresh concrete. The pressure over time is measured at the front surface of the piston. The pipe position over time and therefore the speed or pumping rate is measured with an ultrasonic distance meter. The pipe filled with fresh concrete is lifted up by hand and sliding down only driven by the gravity. Two simulate different pumping rates and pressures different weights are fixed at the pipe. Usually you start with the weight of the pipe itself. After a series of three strokes a weight of 1.5 kg is added for the next 3 strokes. This procedure is repeated five times, so finally 7.5 kg are forcing the pipe speed and also the pressure. The pipe is transparent, so its possible and recommended to inspect the concrete-pipe interface zone. The pressure and position date of each stroke are measured and digitized 500 times per second and transferred wireless to a common Smartphone.
There the data are stored and displayed graphically.

*Fig-1a: The SLIPER*

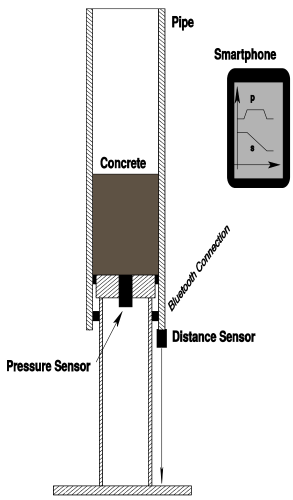


*Fig-1b: Sliper operation principle*

The system is portable, robust, and designed to work on a construction site as well. This evaluation system permits a precise description of fresh concrete characteristics, thus allowing the user to arrive at reliable prognoses for the projected pumping application. To accomplish this, a calculation model has been provided that allows the Sliper system to be used for the predetermination of pressure losses in concrete pumps.After the measurement procedure the pipe can divided in two parts for easy draining the concrete. Figure 2 shows a sketch of the measurement, filling and cleaning process

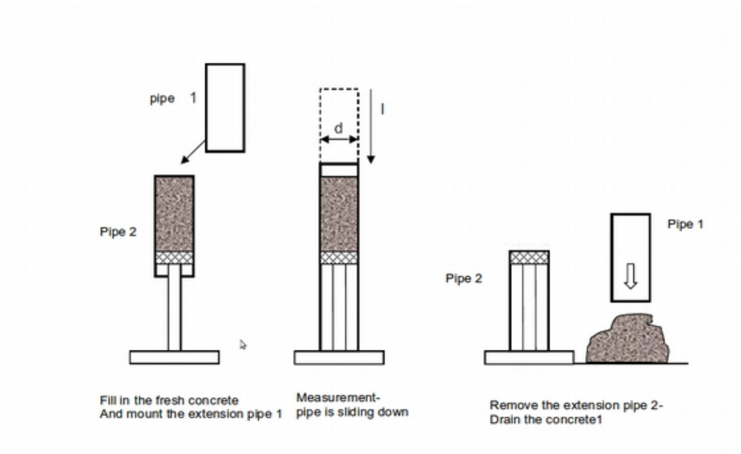


*Fig-2: The test procedure*

## 3.2 Data Evaluation

Figure 3a shows the pressure over time for 2 strokes with different weights and the calculated maximum pressure $p_i$. Figure 3b the according pipe falling position over time and calculated speed. The maximum pipe speed $vmax_i$ multiplied by the pipes volume $V$ gives the maximum pumping rate $Q_i$ for each stroke $i$.
For each stroke the maximum pressure value $p_i$ and the maximum pumping rate $Q_i$ is evaluated. Usually $p_i$ and $Q_i$ are increasing with the increasing load by the additional weights. Finally the tuples $(Q_i, p_i)$ are plotted in a $Q/p$ diagram. Its remarkable that for most concretes the pressure $p$ in increasing linear with the pumping rate $Q$. So we can interpolate this data point by a line which is described by the slope $B$ and the intercept $A$. Following the theory of Kaplan [3] the influence of the geometry may be eliminated by $a = d\, A / (4\, l)$ and $b = B\, \pi\, d^3 / (16\, l)$ where $d$ is the pipe diameter of the SLIPER (125 mm) and $l$ is the length of the pipe (500 mm). The curve defined by the yield-pressure $a$ and the pressure-gradient $b$ are characterizing the pumpability of a concrete similar as a flow curve.

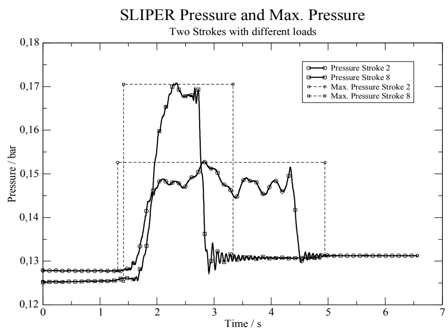


*Fig-3a: pressure vs. time*

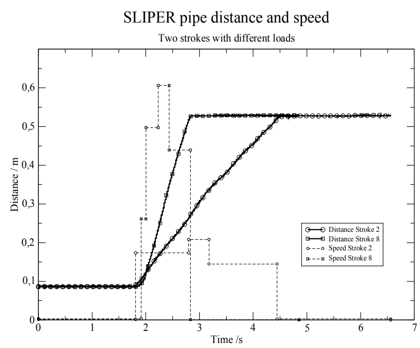


*Fig-3b distance vs. time*

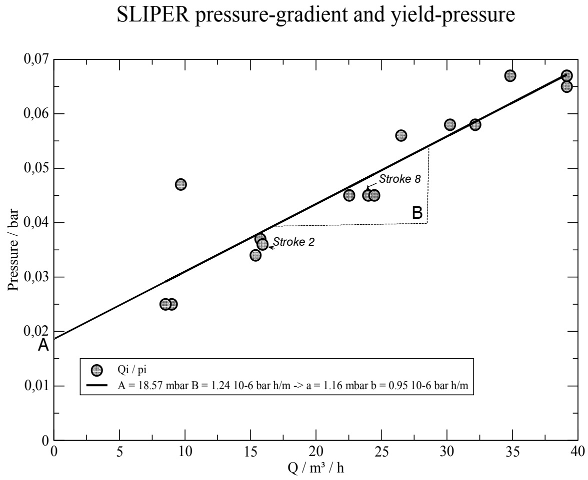


*Fig-4*

## 3.3 Pumpability Forecast

Based on the known yield-pressure *a* and pressure gradient *b* the software app of the SLIPER can calculate a forecast of the maximum displacement volume at a given maximum pressure or vice versa. As input the the pipe length and diameter as well as the bulk density of the concrete is required. Figure 7 shows an example for mix M2.

## 4.0 Application Example

At the University of Technology, Dresden, Germany a test program was done to proof the technical design and software of the SLIPER.

## 4.1 Used Material and Mix Designation

Six different mortars and concretes have been tested. Two different types of sand (crushed and natural sand) with and without fly ash in a standard and self compacting mix design. Table 1 shows the different mixes.

| | Slump flow /mm | Air content / % | Density /kg/m³ | w/p | Max aggregate size /mm | Volume of aggregates |
|---|---|---|---|---|---|---|
| M1[1] | 500.00 | 3.90 | 2.19 | 0.50 | 4.00 | 0.56 |
| M1F[1*] | 567.50 | 3.50 | 2.18 | 0.50 | 4.00 | 0.56 |
| M2[2] | 510.00 | 3.70 | 2.29 | 0.50 | 5.00 | 0.56 |
| M2F[2*] | 535.00 | 4.20 | 2.20 | 0.50 | 5.00 | 0.56 |
| SCC | 885.00 | 2.60 | 2.15 | 0.29 | 4.00 | 0.39 |
| SCM | 790.00 | 4.30 | 2.11 | 0.29 | 2.00 | 0.39 |

[1] rounded aggreates
[2] crushed aggreates
[*] Replacement of 20 % by mass of cement through fly ash

*Table 1*

## 4.2 Used Measurement Instruments

The following test instrument have been applied:

- SLIPER (2 instruments to proof the repeatability
- Contec Viscometer for fresh concrete
- eBT2 Concrete Rheometer
- Slump flow table
- Air content pressure meter

| | Contec Viscometer | | Sliper 1 | | Sliper 2 | | eBT2 1. Meas. | | eBT2 2. Meas. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | τ0 / Pa | μ /Pa·s | a / mbar | b / 10⁻6 bar h/m | a / mbar | b / 10⁻6 bar h/m | τ0 / Nmm | μ /Nmm min | τ0 /Nmm | μ /Nmm min |
| M1[1] | 97.06 | 5.54 | 0.758 | 0.646 | 0.799 | 0.683 | 70.2 | 90 | 67.6 | 178 |
| M1F[1*] | 61.34 | 4.62 | 0.522 | 0.54 | 0.631 | 0.556 | 18.3 | 862 | 19.6 | 79 |
| M2[2] | 97.36 | 5.84 | 0.807 | 0.742 | 0.803 | 1.13 | 71.1 | 81 | 71 | 37 |
| M2F[2*] | 79.36 | 4.33 | 0.832 | 0.537 | 0.666 | 0.711 | 60.9 | 502 | 62.9 | 183 |
| SCC | 2.30 | 14.89 | -0.065 | 2.252 | 0.411 | 2.098 | 13.2 | 633 | 11.4 | 761 |
| SCM | 7.23 | 20.65 | 0.145 | 2.03 | | | 11.2 | 1190 | 12.9 | 856 |

*Table 2*

Table 2 shows the numerical results. For the SLIPER the measured yield-pressure *a* and pressure-gradient *b* is shown. Keeping in mind that there are about 10 minutes between the measurements at Sliper 1 and Sliper 2 the reproducibility is quite satisfying. Figure 6 and 7 show a screenshot from measured pressure and stroke height over time, figure 4 $Q_i/p_i$ diagram for mix M2.

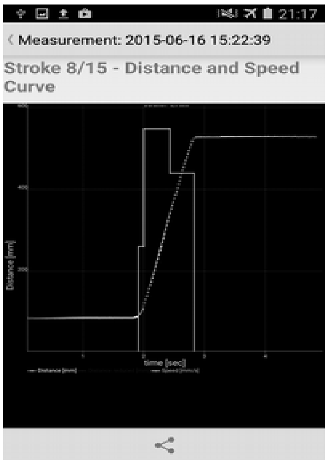


*Fig-5: distance vs. time*

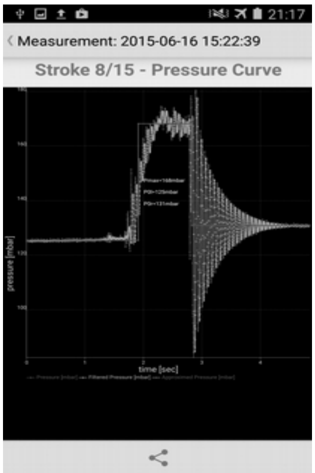


*Fig-6:pressure vs. time*

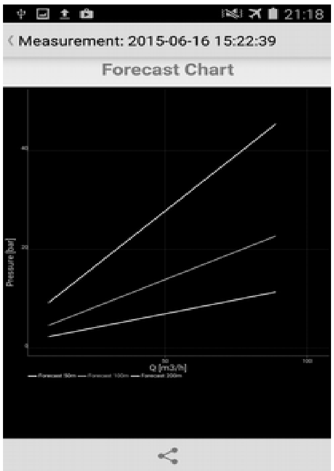


*Fig-7:pumpability forecast*

## 5.0 SLIPER vs. Rheometer

The correlation between pumpability and rheology, specially the Bingham parameters is still an open topic [4, 5]. In figure 8 the correlation between the yield value, measured with the Contec rheometer and the yield-pressure a measured with Slipers1 is shown. The same is done between the pressure-gradient and the viscosity.

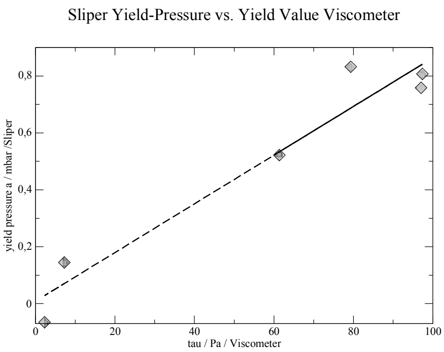


*Fig-8: yield stress vs. a*

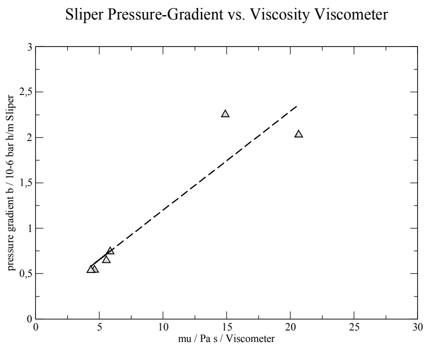


*Fig-9: viscosity vs. b*

## 6.0 Conclusion and Outlook

The pumpability of fresh concrete is a very critical factor and important for nearly all applications of concrete. With the modern concretes like SCC and UHPC its getting still more critical. Standard flow testing methods like the slump flow are not sensitive and accurate enough to predict the pumpability. The Sliper is, as far as we know, the first mobile, battery driven robust instrument, designed for the field which is specially designed to forecast the pumpability of concrete.

## 7.0 Acknowledgements

We are thanking Knut Kasten from Putzmeister for his ingenious invention. Licensing the patent to Schleibinger makes this technology available for all concrete engineers world wide. We are also thanking E. Segrieru and V. Mechtcherine and their team at the TU Dresden, Germany, for the opportunity for exhaustive tests in their well equipped concrete lab.

**List of References**

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