University of Twente

Bachelor Thesis

Research on internal suffosion and fluidization of glass beads

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Abstract

Faculty of Engineering Technology

Bachelor in Civil Engineering

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by J.J. Jansen

Dams, levees and floodwalls build on permeable sandy soil can be susceptible to failure due to seepage under the structure. This failure can take the form of internal suffosion and fluidization. To increase our understanding of these phenomena laboratory tests on homogeneous glass beads are performed at the Laboratory of Water Structures at the Faculty of Civil Engineering of the Brno University of Technology. In this thesis the currently existing methods to determine the initiation criteria for soil failure due to seepage are compared to the laboratory test results. Methods derived by Terzaghi, Knorre and Zamarin failed to correctly identify the criteria for failure in glass beads. Istominas theory for determining the critical hydraulic gradient approximates the measured critical gradient, but fails to explain the difference in critical gradient for different grain sizes. Experimental results indicate that grain size also influences the criteria for failure. Finally a method for testing the criteria for failure in non-uniform mixtures of glass beads is proposed.

Acknowledgements

This thesis is the final project to finish my Bachelors degree in Civil Engineering at the University of Twente. For this thesis I spent 10 weeks at the Institute of Water Structures of the Faculty of Civil Engineering at the Brno University of Technology. Here I performed research on the internal suffusion and fluidization of glass beads under supervision of David Duchan, from the Institute of Water Structures, and Suzanne Hulscher, from the University of Twente.

First of all I want to thank my supervisors. I would like to thank David Duchan for his guidance and his help during the research. I want to thank Suzanne Hulscher for her guidance during this project. Furthermore I want to thank Martijn Booij for recommending the Brno University of Technology to me and supporting me during my placement period.

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At last I would like to thank my family and friends for their support during this period.

Contents

List of Figures

List of Tables

Symbols

A	flow area	m^2
C_u	coefficient of uniformity	-
d_{10}	10% passing grain size	m
d_{30}	30% passing grain size	m
d_{60}	60% passing grain size	m
G	specific gravity	-
J	hydraulic gradient	-
J^C	critical hydraulic gradient	-
K	hydraulic conductivity	m/s
K_S	hydraulic conductivity in the saturated zone	m/s
$K_{S,0}$	hydraulic conductivity in the saturated zone before failure	m/s
L	length of the sample	m
q	specific discharge	m/s
q^C	critical specific discharge	m/s
Q	discharge	m^3/s
R^2	coefficient of determination	-
Re	Reynolds number	-
T_C	temperature	°C
T_K	temperature	K
v	kinematic viscosity	m^2/s
γ_g	soil particle unit weight	N/m^3
γ_w	unit weight of water	N/m^3
Δ_h	difference between hydraulic heads	m
ϵ	void ratio	-
μ	dynamic viscosity	N·s/m^2
ρ	density	kg/m^3

Chapter 1

Introduction

1.1 Research motivation

Dam failures are rare, but when they occur can lead to immense damage and loss of life. The leading cause of dam failures is from internal erosion through the embankments or subsoil. According to a failure statistic analysis carried out by Foster et al. (2000) 30.5% of all failures of water retention dams were due to internal erosion. According to Richard and Reddy (2007) seepage related failure even accounts for more than 50% of all dam and levee failures.

Internal erosion is especially dangerous for three reasons: first, because there might not be external evidence, or only subtle evidence, that the process is taking place. Once evidence of the internal erosion becomes obvious a dam breach may occur within a few hours.

Second, because there is no given moment when internal erosion may develop. It may develop the first time water is impounded behind a dam, or it may develop many years later. It cannot be assumed that a dam is safe just because it has performed satisfactory in the past.

Third, because internal erosion is a process that is not yet completely understood. With the current knowledge internal erosion cannot be completely analyzed using models or formulae. The formulae that exist are only applicable to a small subset of soils for which the formulae were specifically designed. Because of this the building of earth dams remains an empirical process so far.

For these reasons there is a need for a better understanding of internal erosion. The internal erosion is linked to the seepage rate, which is connected to the hydraulic gradient, internal structure, particle size distribution, etc. Therefore the hydraulic gradient is crucial for embankment stability and the prevention of internal erosion. The process of internal erosion can take many forms, of which the fluidization and internal suffosion forms are examined in this report.

1.2 Objective and research questions

This research was performed at the Institute of Water Structures of the Faculty of Civil Engineering at the Brno University of Technology. Determining the criteria for the initiation of internal suffusion and fluidization is a subject which has fascinated researchers for many decades. Most of the formulae to determine the criteria that exist today are empirical formulae which are only applicable to the kind of soil they were derived from. This research is part of a larger ongoing project at the Institute of Water Structures. The objective of this larger project is to discover a method to determine the criteria for initiation of internal suffusion and fluidization that is applicable to all kinds of soils. For the research for this bachelor thesis experiments will be performed to determine the failure criteria of glass beads. Glass beads are chosen because it can be used to create truly uniform and homogeneous samples, unlike soil samples which will always keep a factor of randomness in it.

The main research question is:
What are the criteria for failure due to upward seepage in glass beads in the saturated zone?

The sub questions are as follows:

1. What are the current methods for determining the initiation criteria for failure due to seepage?
2. What are the initiation criteria in uniform homogeneous mixtures of glass beads?
3. How should experiments on non-uniform mixtures of glass beads be performed?

1.3 Outline of report

The structure of the report is as follows. In chapter 2 the problem is analysed and the different forms of deformation due to seepage are explained in detail. In chapter 3 the theoretical background on groundwater hydraulics and the statistical analysis will be explained. The methods for determining the hydraulic conductivity and the critical hydraulic gradient will be described in this chapter. Chapter 4 will describe the experiments performed for this research. The sample material and its preparation and the apparatus will be described.
Chapter 5 will show the analysis of the measurements obtained from the experiments. First the hydraulic conductivity for the samples is determined. Next the hydraulic gradients of the samples are analysed and the critical gradient is determined using two different methods. Lastly the measured critical gradients are compared to the calculated critical gradients obtained from the equations described in chapter 3.
Chapter 6 proposes a method for performing experiments on non-uniform mixtures of glass beads to be used in a follow-up research.
In chapter 7 the results from the experiments and the experiment procedures will be discussed. Finally chapter 8 will provide the conclusions and recommendations obtained from this study.

Chapter 2

Problem analysis

Upward seepage at the downstream toe of hydraulic structures such as dams or levees can result in the initiation of deformation of non-cohesive soils at the base. This deformation due to seepage can take many forms and many authors who studied the problem formulated their own categorizations of deformation. The most comprehensive and accepted classification is defined by Istomina (1957) and was complemented by Vuković and Pušić (1992). This classification is as follows:

Fluidization
: Fluidization is a form of soil failure where part of the porous medium is moved en masse due to the forces exerted by upward seepage.

Suffosion
: Suffosion is a form of failure where fine particles are moved through a matrix of larger soil particles and flushed out leaving behind a coarser soil structure.

Erosion
: Erosion is a process where grains are removed along the preferential paths of water flow. The flushed material will be brought to the surface, into a stream, or into fissures and voids within the ground.

Clogging
: Clogging is a process which involves filling of voids with fine particles, this leads to smaller voids and hence lower seepage rates. The fine particles can come from surface water, bearing suspended load, or can be biological or chemical in origin.

Interface fluidization
: Interface fluidization is a form of deformation of the porous medium at the interface with a coarse soil material. Due to upward seepage perpendicular to the interface plane fine particles travel upwards and penetrate the pores of the coarse material. This results in the formation of a new stratum with a different mechanical composition and properties.

Interface erosion
: Interface erosion is a form of deformation at the contact point between fine and coarse

materials due to water seepage along the interface. Similar to interface fluidization this will result in the formation of a new layer with different characteristics.

Exfoliation

Exfoliation only occurs in coherent soils and results in reduced cohesion, increased volume and a higher surface moisture in areas where the soil is not loaded with any ballast.

All the above forms of failure can happen alone, but simultaneous occurrence of several forms of failure is also relatively common. This report will only focus on the first two forms of deformation; fluidization and suffosion. The next two paragraphs will explain the fluidization and suffusion processes in further detail.

2.1 Fluidization

In the fluidization process a certain volume of the porous medium is moved due to the upward seepage. When the hydraulic gradient reaches the critical point the upward drag on the soil particles imparted by the water is high enough to lift their weight. The particles then float as a suspension becoming a fluidized bed. This results in an increased bulk volume, porosity and pore sizes of the porous medium. According to Zamarin (as cited in Vuković and Pušić (1992)) the fluidization may take one of the following two forms:

- General and simultaneous suspension of a portion of the soil mass
- Local failure in the form of boiling

The local forms of fluidization can result in a process called piping or backwards erosion. This is a process involving the detachment of soil particles when the seepage exits to a free unfiltered surface. The process of piping or backwards erosion as described by Fell and Fry (2007) involves the detachment of soil particles when the seepage exits to a free unfiltered surface. Soil particles are carried by the seepage flow. This process gradually works its way upstream until a tunnel or pipe is formed as shown in figure 2.1.

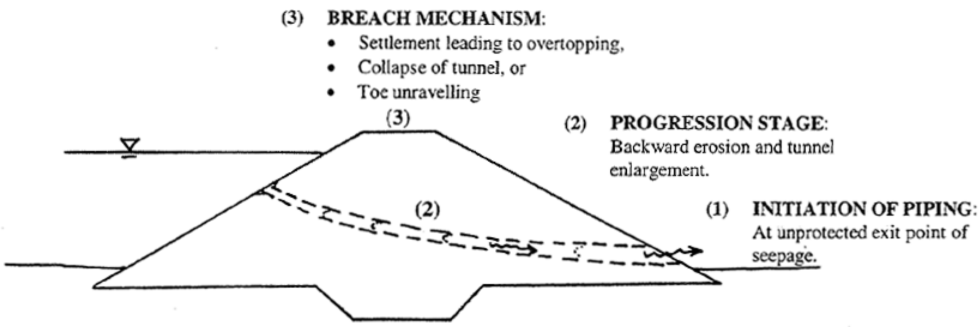

FIGURE 2.1: Stages of development of piping failure (Foster et al., 1998)

2.2 Suffosion

Suffosion (also called suffusion) is a form of failure caused by the removal of fine grains from the soil due to seepage. This form of failure generally only occurs in porous medium of nonuniform grain-size composition. In this process finer soil particles are moves through a matrix of larger soil particles by seepage forces. When the finer soil particles are flushed out a coarser soil structure will be left behind (figure 2.2). This leads to increased permeability and seepage, progressive deterioration of the structure, and a higher risk of instability (Fell and Fry, 2007).

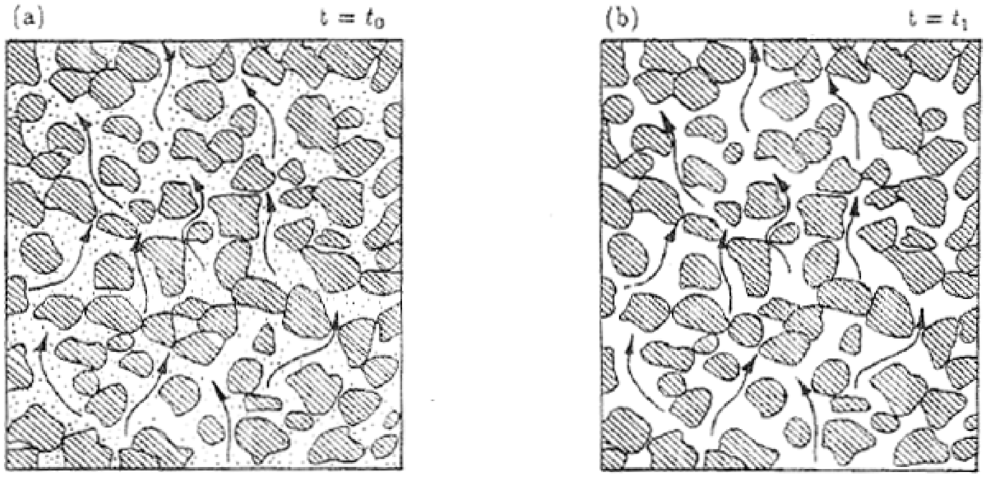

FIGURE 2.2: Internal suffosion: a. Beginning of the process, b. End of the process. (Vuković and Pušić, 1992)

Chapter 3

Theoretical background

3.1 Hydraulics of groundwater

The first research on patterns of groundwater flow was done by Darcy (1856), who has derived formulae describing the flow through porous media. Another key author on groundwater flow hydraulics is Bear (1988).

3.1.1 Darcy's law

Darcy's law is an equation that describes the flow of a fluid through a porous medium. The basic form of the Darcy equation is as follows:

$$Q = -KA\frac{\Delta h}{L} \tag{3.1}$$

Where Q is the discharge [m^3/s], K is the hydraulic conductivity [m/s], A the cross-sectional area of the flow [m^2], Δh the difference between hydraulic heads [m], and L the length of the sample [m]. Equation (3.1) can be rewritten as:

$$q = -KJ \tag{3.2}$$

$$q = \frac{Q}{A} \tag{3.3}$$

$$J = \frac{\Delta h}{L} \tag{3.4}$$

Where q is the specific discharge [m/s] and J is the hydraulic gradient [-]. Darcy's law is valid for linear laminar flow through soil. When the Reynolds number gets higher the flow goes from linear laminar flow to non-linear laminar flow and eventually to turbulent flow. The different flow phases are illustrated in figure 3.1.

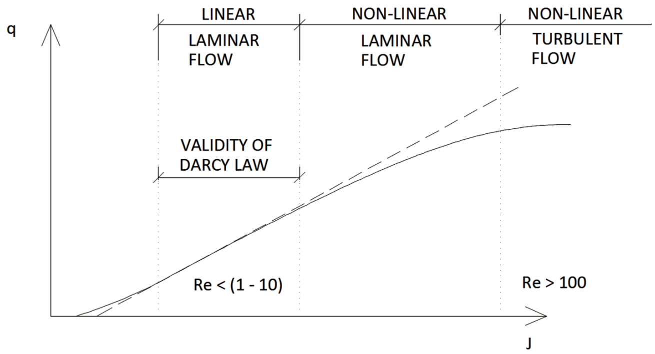

FIGURE 3.1: Range of validity of Darcy's law

As is shown in figure 3.1 the linear relationship between the hydraulic gradient J and the specific discharge q as described by Darcy's law is only valid for flow with a small Reynolds number. According to Bear (1988) the upper limit for the Reynolds number lies between 1 and 10. The increasing ratio between J and q for larger Reynolds numbers is shown in figure 3.2.

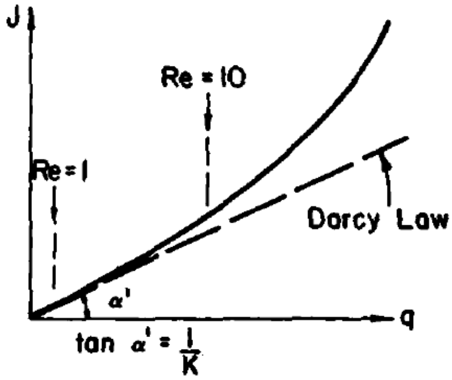

FIGURE 3.2: Schematic curve representing experimental relationship between specific discharge and hydraulic gradient (Bear, 1988)

For the non-linear laminar flow with a Reynolds number between 10 and 100 a modification of Darcy's law will be used. Many authors, such as Forchheimer, White, Polubarinova-Kochina and Scheidegger have suggested formulae to describe the nonlinear relationship between J and q at large Reynolds numbers (Bear, 1988). Forchheimer was the first to suggest a nonlinear relationship and his equation will be used in this report. The Forchheimer equation for one-dimensional motion is as follows:

$$J = Wq + bq^2 \tag{3.5}$$

Where W and b are constants, and:

$$W = \frac{1}{K} \tag{3.6}$$

A graphical representation of the Forchheimer equation is shown in figure 3.3.

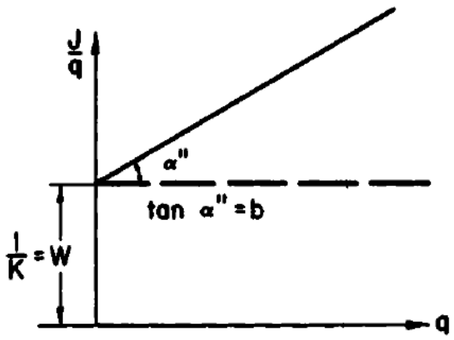

FIGURE 3.3: Graphical representation of Forchheimer equation (Bear, 1988)

3.1.2 Reynolds number

The equation to determine the Reynolds number for groundwater flow is as follows:

$$Re = q\frac{d}{v} \tag{3.7}$$

Where d_{30} is the representative grain diameter of the porous media [m] and v is the kinematic viscosity [m^2/s]. The representative grain diameter is taken as the 30% passing size from a sieve analysis. The kinematic viscosity is calculated as shown below:

$$v = \frac{\mu}{\rho} \tag{3.8}$$

Where μ is the dynamic viscosity [Ns/m^2] and ρ is the density of the water [kg/m^3]. The dynamic viscosity is calculated with the Vogel-Fulcher-Tammann-Hesse equation which takes the form of:

$$\mu = e^{A+\frac{B}{C+T_K}} \cdot 0.001 \tag{3.9}$$

Where A, B and C are constants dependent on the fluid, in this case water, and T_K is the temperature [K]. The values of the constants are retrieved from the Dortmund Data Bank[1].

$$A = -3.7188 \tag{3.10}$$

$$B = 578.919 \tag{3.11}$$

$$C = -137.546 \tag{3.12}$$

The density of the water ρ is dependent on the temperature and is determined with the Thiesen-Schiel-Diesselhorst equation (Martin and McCutcheon, 1998):

$$\rho = 1000\left[1 - \frac{T_C + 288.9414}{508929.2(T_C + 68.12963)}(T_C - 3.9863)^2\right] \tag{3.13}$$

Where T_C is the temperature [°C].

[1] http://ddbonline.ddbst.de/VogelCalculation/VogelCalculationCGI.exe

3.1.3 Critical hydraulic gradient

Many different authors have done research on the maximum possible critical hydraulic gradients. The most well known amongst them are Terzaghi and Istomina.
The forces acting on particles of porous media are explained in detail by Vuković and Pušić (1992). They state that with a prismatic element with a base of elementary dimensions (figure 3.4) which is situated at the emergence of the flow from a homogeneous and isotropic medium, and is assumed that it is in a state of equilibrium, the vertical forces acting on the volume is equal to zero.

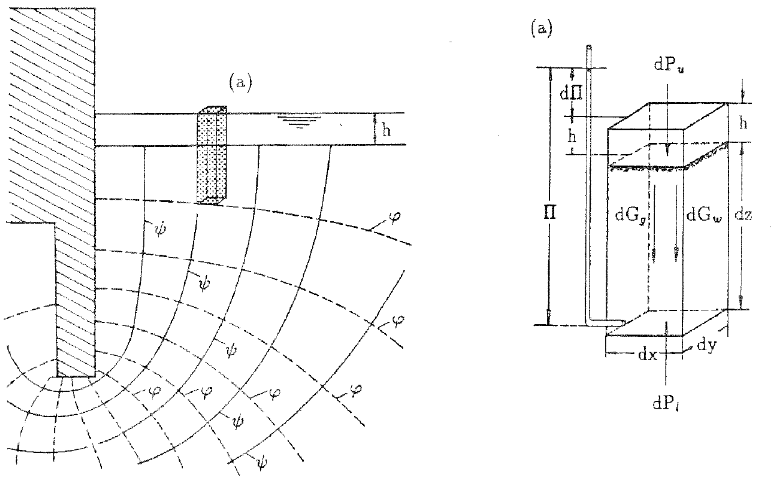

FIGURE 3.4: Definition sketch of equilibrium conditions in a porous medium under the effect of seepage. ψ- streamlines, φ- equipotential lines (Vuković and Pušić, 1992)

According to Vuković and Pušić the acting vertical forces are as follows:

- Weight of the porous medium material (particles) of the elementary volume

$$dG_g = \gamma_g \cdot (1 - n) \cdot dx \cdot dy \cdot dz \tag{3.14}$$

- Weight of water in the pores of the elementary volume

$$dG_w = \gamma_w \cdot n \cdot dx \cdot dy \cdot dz \tag{3.15}$$

- Hydrostatic pressure acting on the upper surface of the elementary volume

$$dP_u = \gamma_w \cdot dx \cdot dy \cdot h \tag{3.16}$$

- Hydrostatic pressure acting on the lower surface of the elementary volume

$$dP_l = \gamma_w \cdot dx \cdot dy \cdot (dz + h + d\Pi) \tag{3.17}$$

Where γ_g is the volume weight of the porous media [N/m^3], γ_w is the volume weight of water [N/m^3], and n is the porosity. The equilibrium condition is as follows:

$$dP_u + dG_g + dG_w \geq dP_l \tag{3.18}$$

By substitutions in equation (3.18) the equilibrium condition can be written as:

$$\frac{d\Pi}{dz} \leq \frac{\gamma_g + \gamma_w}{\gamma_w} \cdot (1-n) \tag{3.19}$$

where

$$\frac{d\Pi}{dz} = J \tag{3.20}$$

This means that the state of equilibrium will be broken when

$$J^C = \frac{\gamma_g + \gamma_w}{\gamma_w} \cdot (1-n) \tag{3.21}$$

Formulae by other authors for determining critical gradients are described by Istomina (1957). Knorre recommended the following formula to determine the critical gradient for failure due to upward seepage:

$$J^C = \frac{\gamma_g + \gamma_w}{\gamma_w} \tag{3.22}$$

Terzaghi performed experiments and studied the stability of sand during upward seepage and proposed the following formula for estimating the critical gradient:

$$J^C = \frac{(\gamma_g + \gamma_w)(1-n)}{\gamma_w} \tag{3.23}$$

This is the same formula as Vuković and Pušić described as a result of the equilibrium of acting vertical forces.

Zamarin carried out experimental and theoretical analyses and proposed the following formula for the critical gradient:

$$J^C = \frac{(\gamma_g + \gamma_w)(1-n)}{\gamma_w} + 0.5n \tag{3.24}$$

Goldstein proposes the following formula for identifying the critical gradient to initiate soil liquification:

$$J^C = \frac{(\frac{\gamma_g}{\gamma_w - 1})}{1+\epsilon} \tag{3.25}$$

Where ϵ is the void ratio [-]. By substituting $\epsilon = n/(1-n)$ equation (3.25) becomes the same as equation (3.23).

Harza (1935) proposed the following formula to determine the criterion of a quick condition in a homogeneous soil deposit:

$$J^C = \frac{G-1}{1+\epsilon} \tag{3.26}$$

Where G is the specific gravity of the porous media [-]. By substituting $G = \gamma_g/\gamma_w$ and $\epsilon = n/(1-n)$ equation (3.26) becomes the same as equation (3.23).

Istomina performed experiments on over 20 different natural materials. This resulted in a relationship between the critical gradient J_{crit} and the coefficient of uniformity C_u. Unlike the previous formulas used to determine the critical gradient this method is not dependent on the volume weight of the porous media but instead on the grain-size distribution. The coefficient of uniformity C_u is defined as:

$$C_u = \frac{d_{60}}{d_{10}} \tag{3.27}$$

Where d_{60} and d_{10} are respectively the 60% and 10% passing size from a sieve analysis [m]. For a homogeneous material this results in a C_u of 1. The resulting relationship between J_{crit} and C_u is shown in figure 3.5. The corresponding critical gradient to a coefficient of uniformity of 1 is also 1.

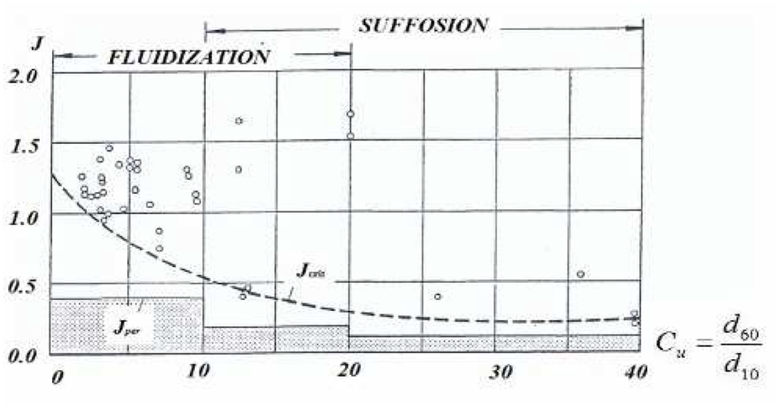

FIGURE 3.5: Plot of $J_{crit} = f(C_u)$ (after Istomina (1957))

Istomina also noticed that after failure of the soil sample there will be a new steady hydraulic gradient. Steady gradients were considered to exist due to residual resistivity of a soil. Even after failure a soil sample would be able to sustain this certain gradient, though this gradient was clearly lower than the critical gradient.

3.2 Statistics

In the statistical analysis the measurements obtained from the experiments will be tested for normality. To test if the values of the critical hydraulic gradient come from a normal distribution three tests will be used. Many tests exist, for this research the tests being used are the Kolmogorov-Smirnov test and two refinements of this test, namely the Lilliefors test and the Anderson-Darling test.

The Kilmogorov-Smirnov test is normally used to compare the distributions of two samples but can be modified to become a goodness of fit test for normality by standardizing the samples and comparing it with a standard normal distribution.

Chapter 4

Experimental research

For this research series of experiments are performed on samples of homogeneous glass beads to determine the critical point of seepage failure in the saturated zone. These experiments were carried out at the Laboratory of Hydraulic Research of the Brno University of Technology. The experiments were performed on compacted and uncompacted samples of homogeneous glass beads with a diameter of 1 and 2 millimeter.

4.1 Sample material

The sample material being used for the experiments are glass beads. The two types of glass beads are specified by the producer to have a diameter of 1 and 2 millimeter. The diameters of 16 (2mm) and 50 (1 mm) glass beads were measured to determine the true diameter of material. The other physical properties being determined are the density and the porosity for compacted and uncompacted samples. The results are shown in table 4.1.

TABLE 4.1: Properties of tested materials

ID	***compacted***	***d*** *[mm]*	***average diameter*** *[mm]*	***average porosity*** *[-]*	***average density*** *[kg/m^3]*
A	yes	2	2.04	0.376	1600
B	no	2	2.04	0.388	1600
C	yes	1	0.95	0.366	1584
D	no	1	0.95	0.387	1584

4.2 Apparatus

For the experiments a constant head permeameter is used. The experiment set-up consists of a constant head tank with a variable height, a reservoir, and a cylinder with the material sample. By raising or lowering the constant head tank the hydraulic head, as measured by the piezometers, can be changed. In figure 4.1 a schematic representation of the experiment set-up is shown.

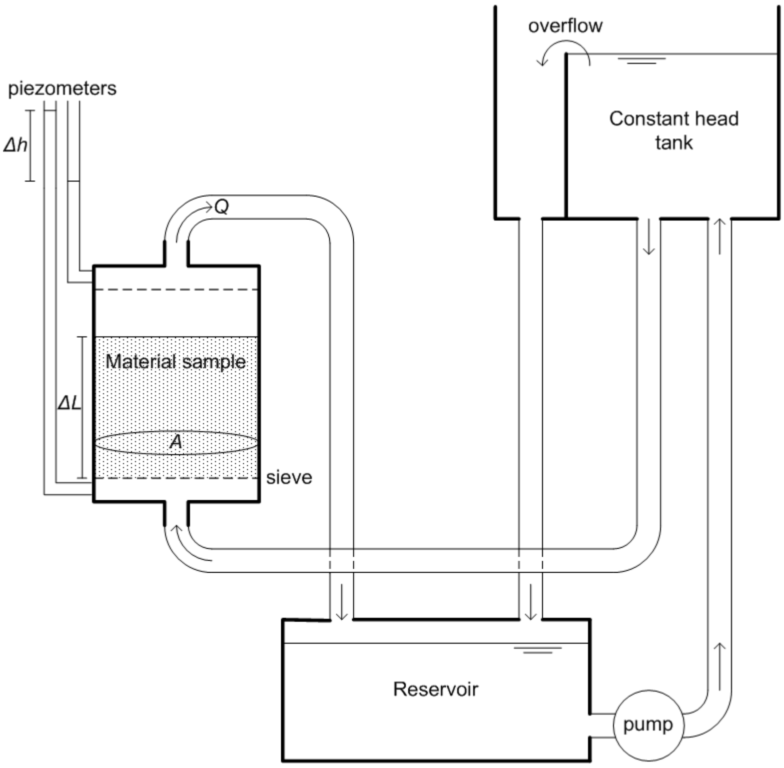

Figure 4.1: Schematic representation of apparatus

The sample is loaded in a clear plastic cylinder with a flow area of 0.01188 m^2. In figure 4.2 a cylinder filled with a material sample and connected to the apparatus is shown.

Figure 4.2: Cylinder containing sample

4.2.1 Limitations of the apparatus

There are some limitations to this apparatus that can influence the measurements. The constant head tank is raised by a lever connected to a gear and a gear stopper. This means that the minimal amount the tank can be raised by is determined by the cogs on the gear. This can result in overshooting the critical hydraulic gradient and going straight to failure.

4.3 Sample preparation

To prepare the sample for testing the following steps are being followed:

1. Place a sieve firmly at the bottom of the cylinder. The sieve is placed to prevent sample material from falling down into the water supply pipe.
2. Fill the cylinder with completely dry glass beads. The cylinder is filled so that the sample height is approximately between 100 and 150 millimeters.
3. In case of experiments on compacted samples the cylinder is placed on a shaker for 60 seconds to compact the sample by vibration. For experiments on uncompacted samples this step will be skipped.
4. Install the cylinder on the apparatus making sure the cylinder is tightly sealed and secured.
5. Slowly and gradually raise the constant head tank to fill the cylinder while making sure all the pores are filled with water and no air bubbles remain in the sample.
6. Once water starts flowing from the outlet allow the piezometers to flow to make sure no air bubbles remain in the tubes.

4.4 Measurements

Measurements were carried out on samples of glass beads prepared as described in section 4.3. Measuring procedures are shown in figure 4.3. During the experiment the sample height L [m], the difference in piezometric head dh [m] and the outflowing water volume dV [m3] during the time dt [s] are measured.

The phases the sample material goes through during the experiments are described and illustrated in appendix A.

The results of the measurements are shown in appendix B. Each measurement is classified as before failure, critical point or after failure. In the column 'failure' the following classifications are used:

- 0: before failure
- 1: critical point
- 2: after failure

The measurement with the highest hydraulic gradient in each set is classified as the critical point.

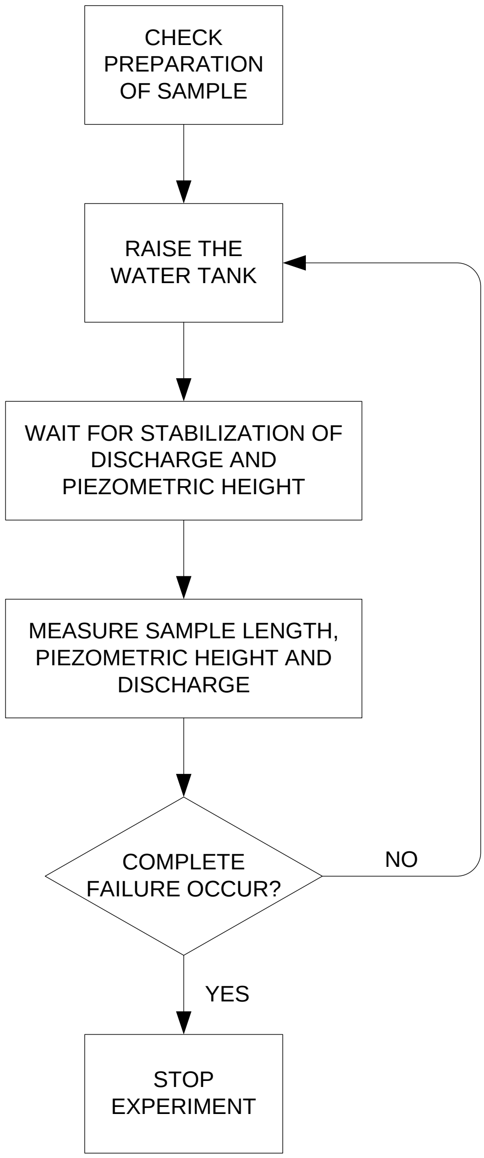

FIGURE 4.3: Measurement steps

Chapter 5

Analysis

In this chapter the measurements obtained from the experiments on samples A,B,C and D are analysed. First the hydraulic conductivity is analysed. Next the critical hydraulic gradient is analysed and compared to the critical gradients calculated using the formulae described in section 3.1.3.

5.1 Hydraulic conductivity

To determine the hydraulic conductivity of the samples first the Reynolds number of the measurements needs to be evaluated. As is shown by the Reynolds numbers of the measurements (see Appendix B) the samples A and B have both linear laminar flow and non-linear laminar flow and the samples C and D experience only linear laminar flow. This means that for samples C and D the hydraulic conductivity can be calculated by using only Darcy's law and for samples A and B Darcy's law as well as Forchheimer equation must be used.

5.1.1 Forchheimer constants

Before the hydraulic conductivity of samples A and B can be calculated the constants of the Forchheimer equation need to be determined for each sample. The Forchheimer constants can be calculated by using one of the formulas described by Sidiropoulou et al. (2007) or can be empirically determined. For this analysis the constants will be empirically determined using the values of the hydraulic gradient J and specific discharge q. To do this q is plotted against J divided by q. Linear regression is then used to model the relationship between q and J/q. The equation of this relationship is derived from equation (3.5) and takes the form of:

$$\frac{J}{q} = Wq + b \tag{5.1}$$

Where W and b are the constants for the Forchheimer equation.

The linear regression for samples A and B are shown in figure 5.1.

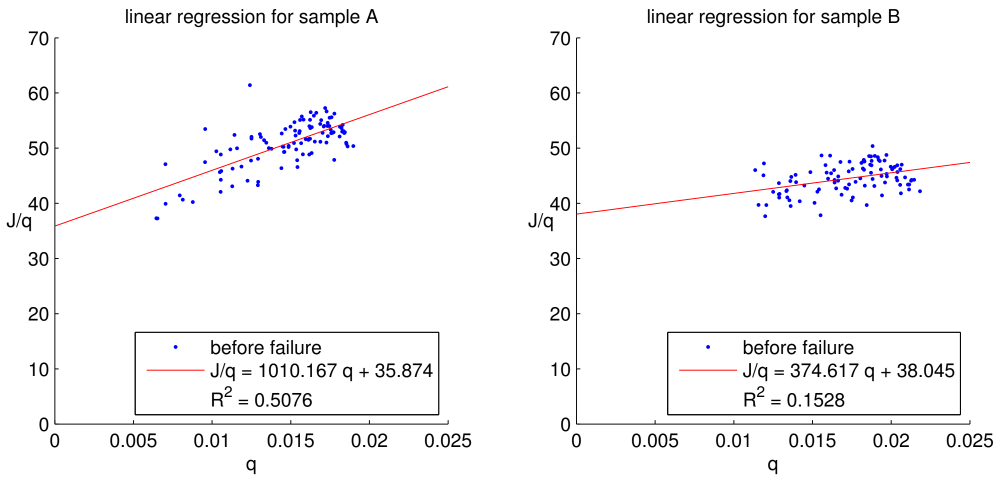

FIGURE 5.1: Linear regression for samples A and B

The constants for the Forchheimer equation for the two samples are shown in table 5.1.

TABLE 5.1: Forchheimer constants

Sample ID	W	b
A	35.874	1010.167
B	38.045	374.817

To use the Forchheimer equation to calculate the hydraulic conductivity equation (3.5) is rewritten as follows:

$$K = \frac{q}{J - bq^2} \tag{5.2}$$

The hydraulic conductivity computed from equation (5.2) for glass beads is shown in table 5.2.

TABLE 5.2: Hydraulic conductivity determined by Forchheimer equation

Sample ID	***Number of measurements***	$K_{S,0Forch}$ *[m/s]*
A	105	0.0279
B	104	0.0262

5.1.2 Distribution

The hydraulic conductivity before failure $K_{S,0}$ was tested for normality using the tests described in section 3.2. The results from these tests showed that $K_{S,0}$ is not normally distributed. The histograms in figure 5.2 show the distribution of $K_{S,0}$.

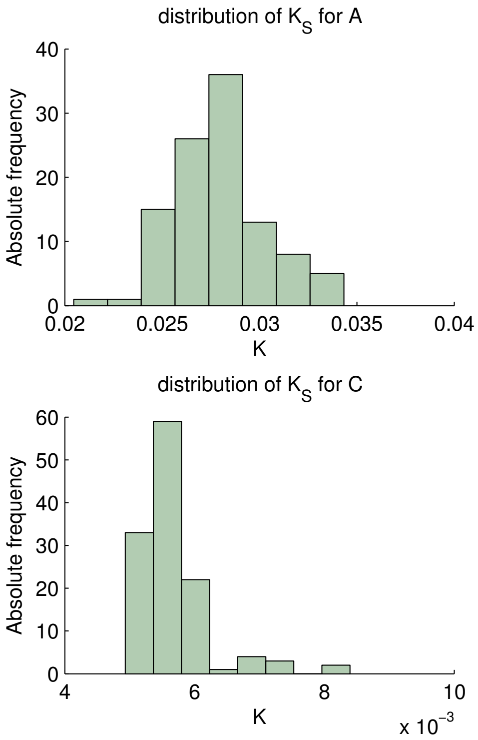

Figure 5.2: Values of K_S before failure

The minimum, maximum and mean values obtained from the histograms and the calculated hydraulic conductivity from the Forchheimer equation are shown in table 5.3. As expected the hydraulic conductivity for the entire sample calculated with the Forchheimer constants (using equation (5.2)) is close to the mean hydraulic conductivity.

Table 5.3: Properties of the saturated hydraulic conductivity

ID	***Number of measurements***	$K_{S,0min}$ *[m/s]*	$K_{S,0max}$ *[m/s]*	$K_{S,0\mu}$ *[m/s]*	$K_{S,0Forch}$ *[m/s]*
A	105	0.0205	0.0343	0.0280	0.0279
B	104	0.0204	0.0312	0.0263	0.0262
C	124	0.0049	0.0084	0.0057	-
D	134	0.0062	0.0062	0.0072	-

5.2 Critical hydraulic gradient

Different types of analysis are performed on the measured values of the critical hydraulic gradient J^C. The first analysis consists of identifying the minimal, maximal and median values of J^C. Next the critical gradient for the samples is determined from the intersection of curves fitted to the measurements of J before and after failure. Lastly a statistical analysis is performed which consists of normality tests and normal distribution fitting.

5.2.1 Interval

The spread of the critical hydraulic gradient is shown in the boxplot in figure 5.3. The blue box represents the data between the first quartile (*Q1*) and the third quartile (*Q3*). The red line indicates the median (or second quartile). The black whiskers represent the data lying between *Q1-1.5IQR* and *Q3+1.5IQR* where *IQR* is the interquartile range and equal to the distance between *Q1* and *Q3*. All the data lying outside of this range are qualified as outliers and represented with a red cross.

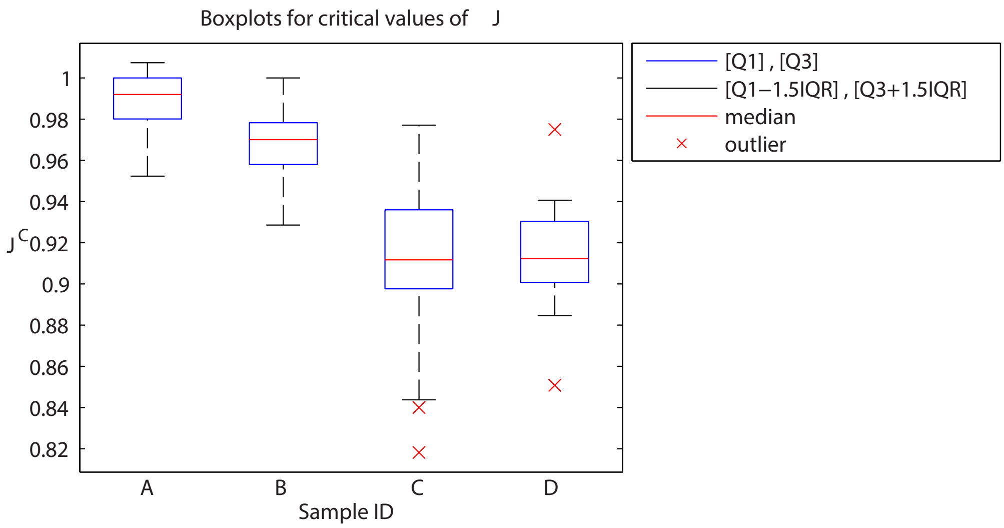

FIGURE 5.3: Boxplot of critical hydraulic gradient

The boxplot shows that for glass beads with a diameter of 2mm the compaction has an influence on the critical gradient (samples A and B). In samples C and D the compaction does not appear to have any influence on the average critical gradient. The compaction of glass beads with a diameter of 1mm seems to have an influence on the spread of the measured gradients as the data of sample C is clearly spread over a wider range than the data in sample D. For further analysis the outliers as identified by the boxplot will be removed and ignored. In table 5.4 the properties of the measured critical hydraulic gradient are shown.

TABLE 5.4: Properties of the critical hydraulic gradient

ID	***Number of measurements***	$J^C{}_{min}$ *[-]*	$J^C{}_{max}$ *[-]*	$J^C{}_{median}$ *[-]*
A	30	0.9524	1.0074	0.9920
B	30	0.9286	1.0000	0.9701
C	28	0.8438	0.9771	0.9177
D	28	0.8846	0.9407	0.9122

5.2.2 Curve fitting

The critical hydraulic gradient for the samples is calculated by curve fitting the relationship between q and J before and after failure. The point where the two curves intersect will then be the critical hydraulic gradient for the samples.

Before failure

Samples A and B will use the Forchheimer equation with the constants calculated in section 5.1.1. Because samples C and D happen within the linear part of Darcy's law a linear curve will be fitted to the q and J before failure.

After failure

As described at the end of section 3.1.3 the material samples will have a residual strength and a steady hydraulic gradient. To correctly describe this phenomenon with the curve fitting the values after failure will be fitted with a power law equation.

In sample D the measurements at the critical point together with the measurements after failure are used to determine the curve after failure. This was done because there are no measurements of sample D right after failure due to the limitations of the apparatus as described in section 4.2.1.

The results of the curve fitting are shown in figure 5.4. The constants and equations used for the curve fitting are shown in table 5.5.

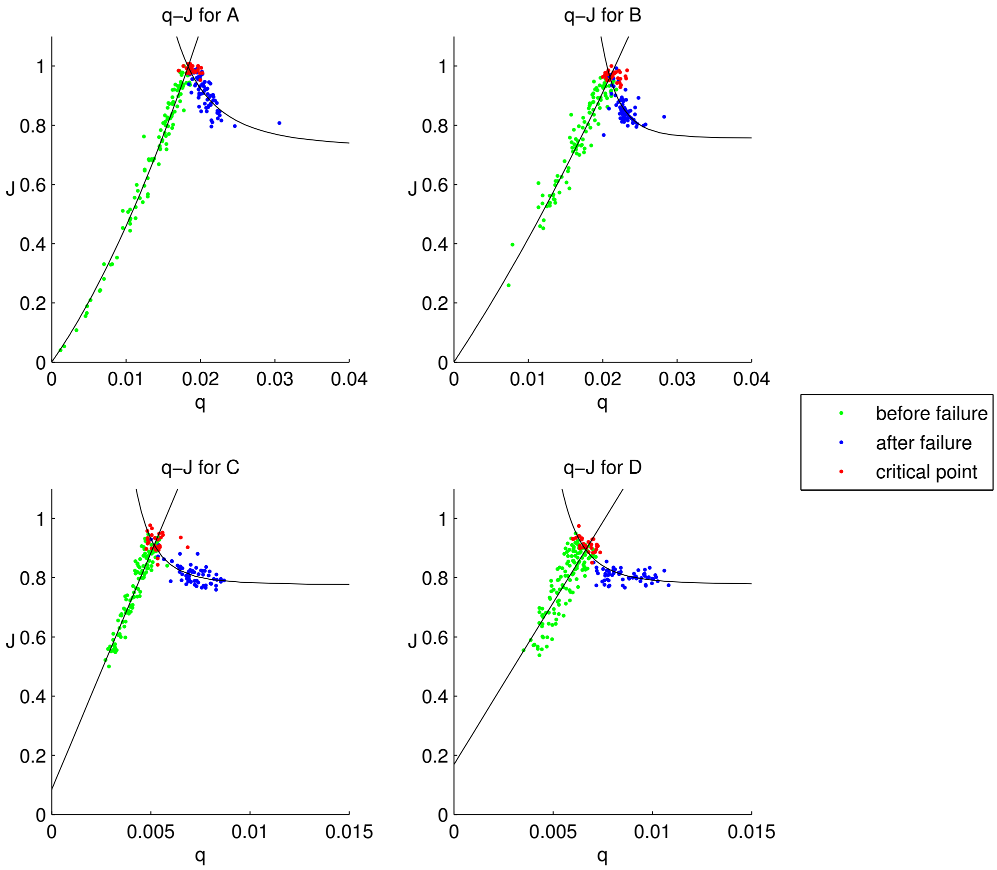

FIGURE 5.4: Curve fitting *q*-*J*

TABLE 5.5: Values for curve fitting

Sample ID	***equation form***	***a***	***b***	***c***	R^2
A: before failure	$J = aq + bq^2$	35.874	1010.167	-	-
A: after failure	$J = aq^b + c$	1.57 * 10^{-7}	-3.595	0.7235	0.5662
B: before failure	$J = aq + bq^2$	38.045	374.817	-	-
B: after failure	$J = aq^b + c$	5.395 * 10^{-16}	-8.688	0.7564	0.6363
C: before failure	$J = aq + b$	159.9	0.08412	-	0.8839
C: after failure	$J = aq^b + c$	4.523 * 10^{-12}	-4.579	0.7761	0.5282
D: before failure	$J = aq + b$	109.3	0.1685	-	0.7281
D: after failure	$J = aq^b + c$	8.004 * 10^{-13}	-5.127	0.7776	0.7266

The critical values of the hydraulic gradient determined by the intersection points of the curves are shown in table 5.6. The specific discharge at the critical point is shown as well.

Table 5.6: J^C for curve fitting

Sample ID	J^C [-]	q^C [m/s]
A	0.9980	0.0183
B	0.9626	0.0210
C	0.9101	0.0052
D	0.8946	0.0066

5.2.3 Statistics

The empirical critical values of the hydraulic gradient obtained from the experiments J_e^C are tested for normality using the methods and tests described in section 3.2. The null hypothesis (H_0) is that the data comes from a normal distribution with a 95% level of confidence. The results of these goodness-of-fit tests are shown in the figures 5.5 to 5.8. The red line indicates the best fitting normal distribution.

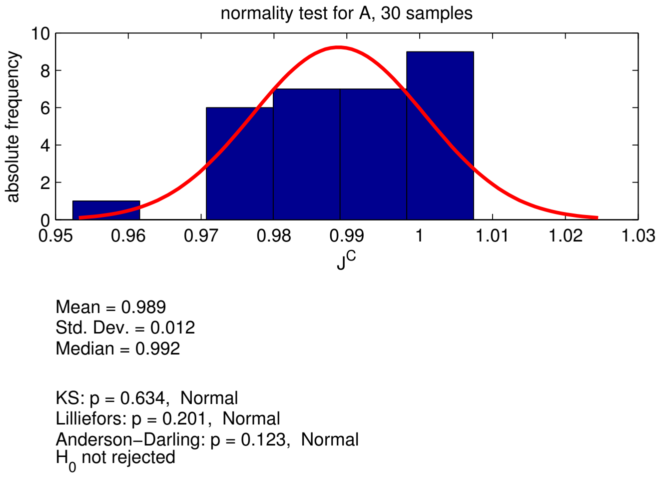

Figure 5.5: Normality tests for sample A

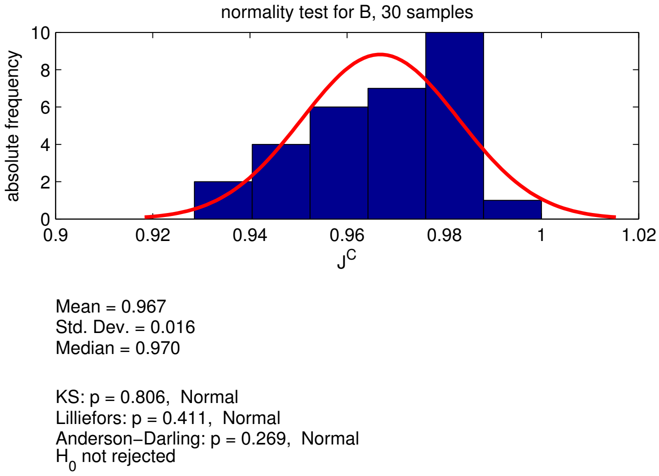

FIGURE 5.6: Normality tests for sample B

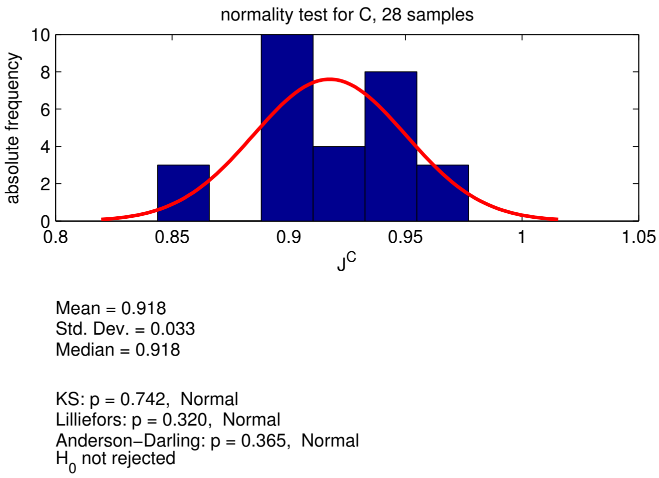

FIGURE 5.7: Normality tests for sample C

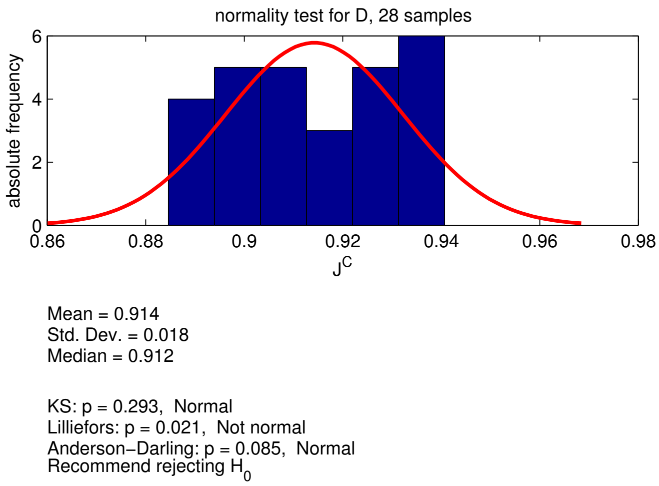

FIGURE 5.8: Normality tests for sample D

The normality tests seem to indicate a possible normal distribution for the critical hydraulic gradient. Sample D is an exception as the Lilliefors test rejects the null hypothesis, but this can also be caused by the relatively low number of measurements. To be able to say with more certainty that the values are normally distributed (statistical power >0.8) the sample size needs to be around 100 (Razali and Wah, 2010). The results of the statistical tests are summarised in table 5.7.

TABLE 5.7: Statistics of critical hydraulic gradient

Sample ID	*Number of tests*	J^C_{median} [-]	J^C_{μ} [-]	J^C_{σ} [-]
A	30	0.992	0.989	0.012
B	30	0.970	0.967	0.016
C	28	0.918	0.918	0.033
D	28	0.912	0.914	0.018

5.2.4 Comparison with theoretical values

The critical hydraulic gradients obtained from the experiments by curve fitting and statistical analysis are compared to the theoretical critical gradients calculated with the equations described in section 3.1.3. Figure 5.9 shows the critical gradients side by side.

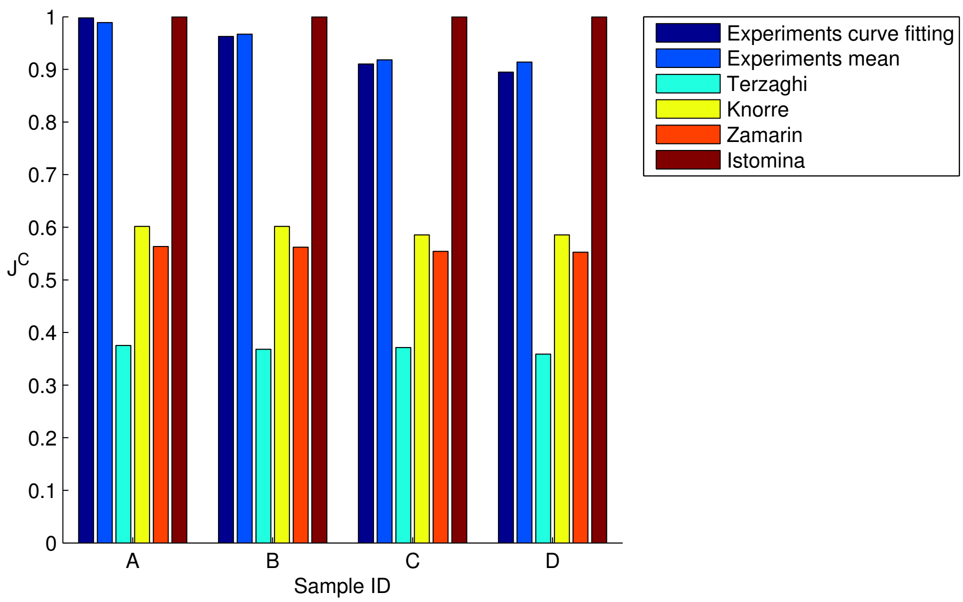

FIGURE 5.9: Comparison of critical gradients

As figure 5.9 shows the theoretical equations underestimate the empirical critical gradient by 35 to 62 percent. The critical gradients proposed by Istomina come closest to the measured values, although the tests indicate that apart from C_u the grain size d also influences the critical gradient.

Chapter 6

Non-uniform mixtures of glass beads

Due to time constraints no experiment sets could be performed with non-uniform mixtures of glass beads to test the criteria for initiation of internal suffosion. To propose a method for preparing and testing samples of non-uniform mixtures one experiment was performed. The sample consisted of glass beads with a diameter of 0.5, 1 and 2 millimeter. The mixture is shown in table 6.1.

Table 6.1: Properties of mixture

Diameter *[mm]*	***part*** *[% by weight]*
0.5	20
1	40
2	40

6.1 Sample preparation

The sample was prepared by weighing the individual grain sizes so that the composition as shown in table 6.1 is achieved. Mixing of the sample was done by hand but due to the smoothness of the glass beads smaller particles tend to migrate to the bottom of the container quickly after mixing. This results in a ”layered” mixture when the material is scooped in the cylinder as shown in figure 6.1. Compacting the mixture by vibration was tried for one sample but this resulted in the migration of finer particles to the bottom of the sample. Compaction by a falling weight might be a possible alternative to compaction by vibration.

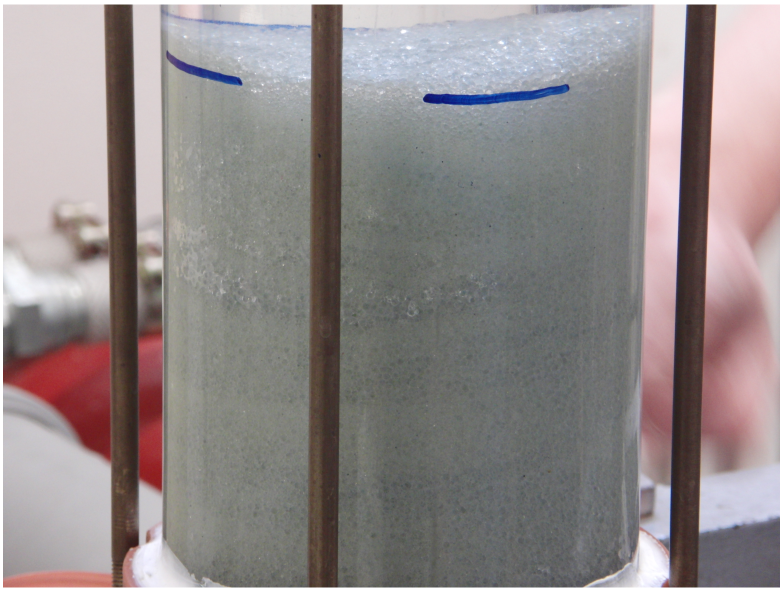

Figure 6.1: Layered appearance of the sample

6.2 Measurements

Results from the experiment are shown in table 6.2. As the comments show the point of failure is not as clearly defined as in the homogeneous mixtures. For continuing research on this subject it should be decided whether to take the first signs of deformation as the critical point even though the gradient is still rising or to take the highest gradient as the critical point i.e. at total failure of the sample.

In the samples consisting of glass beads with a uniform diameter failure only occurs by fluidization. In the experiment with a non-uniform mixture there is a combination of fluidization and internal suffosion. This results is some additional steps of failure not seen in the uniform samples. These steps will now be described using photographs of the experiment. As shown in table 6.2 pockets start to develop at a relatively low gradient of 0.580. This is shown in figure 6.2.

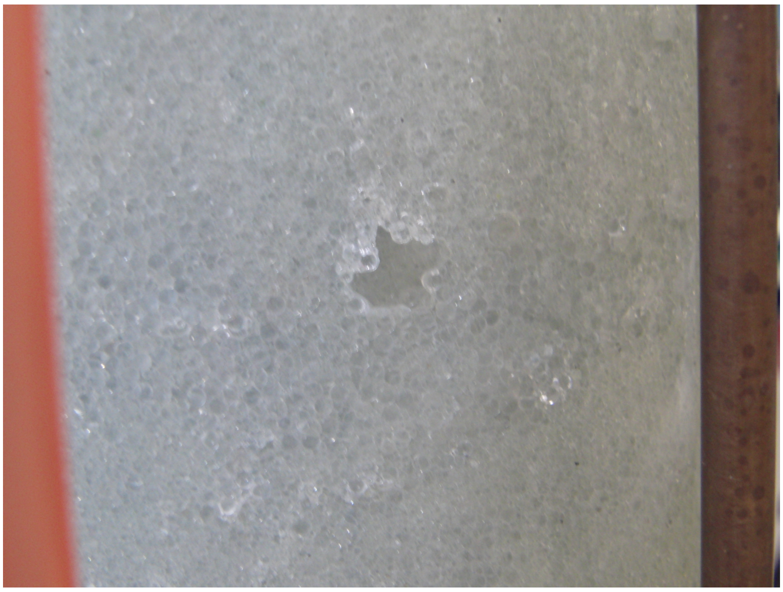

Figure 6.2: Pocket developed in non-uniform sample

At a hydraulic gradient of 0.901 cracks start to develop due to migration of finer particles to the top of the sample. This is shown in figure 6.3. Some air bubbles also appear in the crack.

Figure 6.3: Crack developed in non-uniform sample

The highest hydraulic gradient achieved in this experiment is 0.961. This value lies close to the values obtained from the experiments on uniform mixtures, but it should be noted that this is only the result from a single experiment. More experiments on non-uniform mixtures must be performed to determine the impact of non-uniformity on the critical hydraulic gradient.

Table 6.2: Results of experiment on non-uniform mixture

n.	***dh***	***L***	***dV***	***dt***	***Q***	***K***	***J***	***Re***	***comments***
			10^{-3}		10^{-5}	10^{-3}			
	[m]	[m]	[m^3]	[s]	[m^3/s]	[m/s]	[-]	[-]	
1	0,053	0,150	0,53	39,50	1,34	3,20	0,353	1,19	
2	0,068	0,150	0,55	28,10	1,96	3,64	0,453	1,74	
3	0,087	0,150	0,71	26,85	2,64	3,84	0,580	2,34	pockets develop in the sample
4	0,099	0,150	0,91	30,35	2,98	3,80	0,660	2,64	
5	0,111	0,150	1,22	35,88	3,40	3,87	0,740	3,01	
6	0,123	0,150	0,98	25,78	3,80	3,90	0,820	3,37	
7	0,126	0,150	1,07	26,87	3,98	3,99	0,840	3,53	sample surface levels
8	0,130	0,150	1,08	26,13	4,13	4,02	0,867	3,66	local boiling at fine particles place
9	0,134	0,152	1,07	24,29	4,41	4,21	0,882	3,90	2 mm upheaval, profound boiling on the surface, inner boiling at fine particles layers,
10	0,137	0,152	1,11	24,69	4,50	4,20	0,901	3,99	cracks develop, boiling at surface
11	0,140	0,152	1,00	20,35	4,91	4,49	0,921	4,36	
12	0,145	0,153	0,92	16,10	5,68	5,05	0,948	5,04	cracks develop further, fine particles flushed out
13	0,148	0,154	0,89	15,41	5,78	5,06	0,961	5,12	no cracks, fine particles flushed out, boiling
14	0,146	0,157	1,12	16,43	6,79	6,14	0,930	6,02	complete fluidization of the surface
15	0,137	0,164	1,90	12,57	15,12	15,24	0,835	13,40	

6.3 Research proposal

To determine if the theoretical equations for the critical gradient and especially Istominas theory using the coefficient of uniformity correspond to the measured values I propose the sample types listed in table 6.3 for testing. Istominas theory (as described in section 3.1.3) states that porous media with a C_U smaller than 10 only experience fluidization, media with a C_U between 10 and 20 experience both fluidization and suffosion and media with a C_U higher than 20 only fail by suffosion. By using both well graded and poorly graded samples the effect of soil gradation on the failure can be examined. Lastly each sample will be tested with and without compaction to determine the effects of compaction on the critical hydraulic gradient.

TABLE 6.3: Proposed mixtures for testing

Sample ID	C_U	Gradation	Compacted
A	<10	well graded	yes
B	<10	well graded	no
C	<10	poorly graded	yes
D	<10	poorly graded	no
E	$>10, <20$	well graded	yes
F	$>10, <20$	well graded	no
G	$>10, <20$	poorly graded	yes
H	$>10, <20$	poorly graded	no
I	>20	well graded	yes
J	>20	well graded	no
K	>20	poorly graded	yes
L	>20	poorly graded	no

Chapter 7

Discussion

In this research the current methods to determine the critical hydraulic gradient for failure due to seepage are compared to the measured critical hydraulic gradient obtained from the experiments. Due to time constraints only the samples of 1 and 2 millimeter glass beads were completed.

As written in section 5.2.4 the critical hydraulic gradient proposed by Istominas theory comes closest to the measured values. It also appears that the grain diameter d has an impact on the critical gradient, where smaller grain sizes correspond with a lower critical gradient. Ongoing testing on a new homogeneous compacted sample set E with a grain size of 0.5 mm appears to confirm this. Further testing is needed to confirm or deny this hypothesis.

For continuation of this research it is recommended to continue the experiments on the samples analysed in this report. Due to the relatively low sample size random deviations can have a large impact on the analysis. Furthermore the experiments should be extended to homogeneous materials with smaller diameters e.g. 0.5, 0.2 and 0.1 millimeter.

For further testing the apparatus should also be looked at, specifically the method of raising the water tank. Currently the tank can only be raised in steps (as described in section 4.2.1). This did not appear to affect the measurements of samples A and B. Samples C and D were affected by this limitation, making it difficult to correctly approach the true critical hydraulic gradient. A new method to raise the water tank more gradually should be designed. This is especially important for experiments on materials with smaller diameters.

Despite of the limitations of the apparatus the results from the experiments on glass beads show a much smaller spread than the results on soil samples obtained by Khaddour (2012).

Chapter 8

Conclusions and recommendations

In this research the criteria for the initiation of internal suffosion and fluidization are examined for samples of glass beads. Compacted and uncompacted homogeneous samples of glass beads with 1 and 2 millimeter are examined. Due to time constraints only 30 measurements were performed on sets of 1 and 2 millimeters and no experiment sets for glass beads with a smaller diameter were fully completed.

The current methods to determine the initiation criteria for failure due to seepage consist of theoretical equations derived by Terzaghi, Knorre and Zamarin and an empirical formula derived by Istomina. The theoretical equations derived by Terzaghi, Knorre and Zamarin failed to correctly identify the critical hydraulic gradient as measured in the experiments.

The initiation criteria for failure in uniform homogeneous mixtures of glass beads are specified as the critical value of the hydraulic gradient to initiate failure. The measured critical gradients for samples with a grain size diameter of 1 millimeter were between 0.998 and 0.963. The measured critical gradients for samples with a grain size diameter of 2 millimeter were between 0.918 and 0.895. The calculated critical gradient underestimates the measured critical gradient by 35 to 64 percent. The critical gradients derived from Istominas theory appear to approximate the measured gradients, but on closer inspection there are some deviations. Istominas theory states that the critical gradient is only dependent on the coefficient of uniformity. The measured critical values seem to indicate that the critical gradient is also dependent on the grain size, where smaller grain sizes correspond with a lower critical gradient.

Further experiments on non-uniform mixtures of glass beads must be done to better understand the internal suffosion process. For further research on the internal suffosion it is recommended to perform experiments on twelve sets, where the coefficient of uniformity lies below 10, where the coefficient of uniformity lies between 10 and 20 and where the coefficient of uniformity lies above 20. For each of these ranges there should be a well graded and poorly graded sample so that it can be tested whether or not the distribution has influence on the critical gradient. Each sample should also be tested in a compacted and uncompacted condition.

In conclusion the criteria for failure due to upward seepage in glass beads in the saturated zone are dependent on more parameters than current theories suggest. Determining the criteria for failure by only using the unit weight or coefficient of uniformity of the material is insufficient to correctly identify the criteria. The results from the experiments performed in this research indicate that the grain size also influences the initiation criteria for failure. Further research should be performed to identify the effect size of grain diameter and other possible parameters on the initiation criteria.

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Appendix A

Phases of sample

During the measurements three distinct phases of the material sample can be identified. The first phase is the initial phase. The sample has not yet been deformed by the upward seepage and the hydraulic gradient can still be slowly raised without any impact. Figure A.1 shows the initial condition. The blue marker is added to indicate the starting height of the sample.

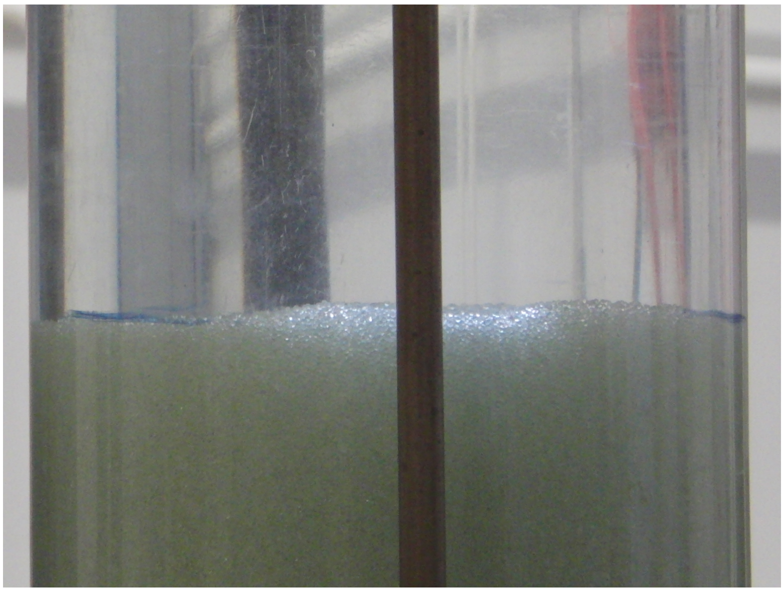

FIGURE A.1: Initial phase of the sample (sample C, testnumber 9, measurement 1)

The next phase is characterized by upheaval of the entire sample. The volume of the sample is increased but the hydraulic gradient is still increasing. The hydraulic conductivity stays relatively constant. As is shown in figure A.2 the top of the sample has risen past the blue marker.

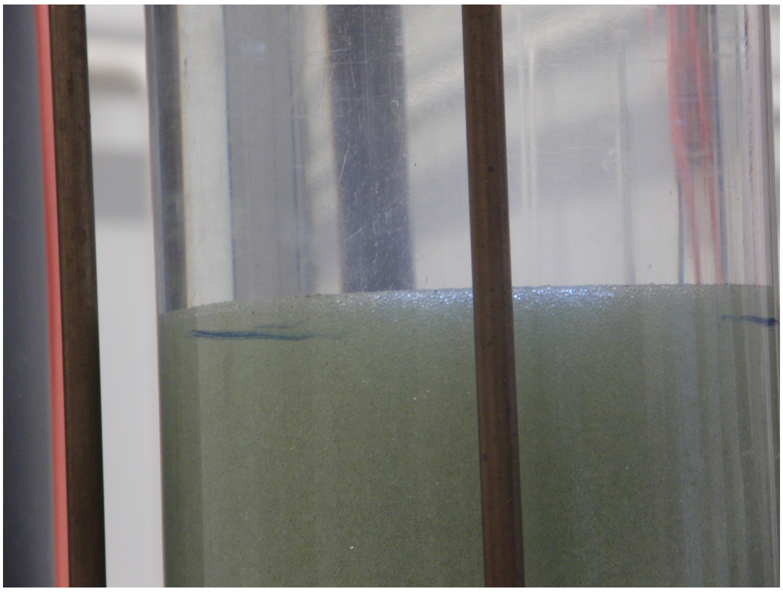

Figure A.2: Upheaval phase of the sample (sample C, testnumber 9, measurement 5)

The third and final phase consists of the complete failure of the sample. After failure the hydraulic gradient rapidly lowers as a result of the increased volume and hydraulic conductivity. The discharge also increases. In figure A.3 boiling can be seen at the top of the sample.

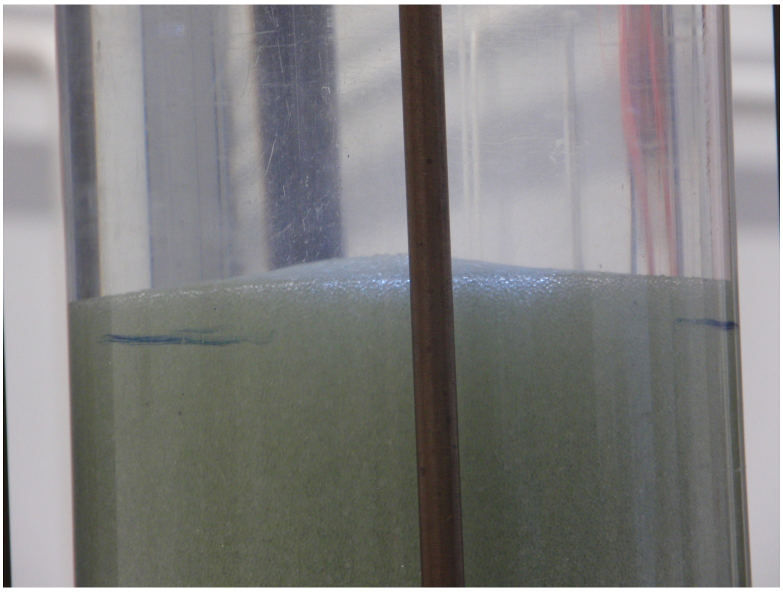

Figure A.3: Failure phase of the sample (sample C, testnumber 9, measurement 6)

Appendix B

Measurements

B.1 Sample A measurements

All measurements were performed with a cylinder with a flow area of 0.01188 m^2 and water with a temperature of 16 ℃.

Table B.1: Measurements of sample A

test	***measure***	***dh*** *[m]*	***L*** *[m]*	***dV*** *10^{-3} [m^3]*	***dt*** *[s]*	***Q*** *10^{-5} [m^3/s]*	***K*** *10^{-3} [m/s]*	***J*** *[-]*	***Re*** *[-]*	***failure***
1	2	0,096	0,124	3,11	17,22	18,06	28,13	0,774	26,68	0
1	3	0,109	0,124	3,39	17,47	19,40	26,81	0,879	28,67	0
1	4	0,114	0,124	3,65	18,89	19,32	24,96	0,919	28,54	0
1	5	0,117	0,124	3,92	18,22	21,51	29,60	0,944	31,78	0
1	6	0,124	0,124	3,88	17,55	22,11	28,64	1,000	32,66	1
1	7	0,121	0,128	3,22	12,82	25,12	42,86	0,945	37,10	2
1	8	0,117	0,134	3,64	14,88	24,46	46,33	0,873	36,14	2
2	1	0,006	0,148	0,30	21,00	1,43	29,67	0,041	2,11	0
2	2	0,016	0,148	0,83	21,00	3,95	30,78	0,108	5,84	0
2	3	0,023	0,148	0,92	17,00	5,41	29,32	0,155	7,99	0
2	4	0,036	0,148	1,28	16,50	7,76	32,64	0,243	11,46	0
2	5	0,049	0,148	1,62	16,75	9,67	30,84	0,331	14,29	0
2	6	0,084	0,148	1,92	12,50	15,36	32,45	0,568	22,69	0
2	7	0,117	0,148	3,46	18,00	19,22	30,78	0,791	28,40	0
2	8	0,150	0,150	4,68	20,00	23,38	32,34	1,000	34,53	1
2	9	0,137	0,157	4,57	18,00	25,39	52,02	0,873	37,50	2
2	10	0,135	0,162	5,10	19,00	26,84	71,23	0,833	39,65	2
3	1	0,010	0,187	0,52	26,00	2,00	31,49	0,053	2,95	0
3	2	0,031	0,187	0,96	17,00	5,62	28,53	0,166	8,30	0
3	3	0,045	0,187	1,38	18,00	7,67	32,51	0,241	11,33	0

Continued on next page

Table B.1 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
3	4	0,066	0,187	1,72	16,50	10,42	31,90	0,353	15,40	0
3	5	0,083	0,187	2,13	17,00	12,53	31,83	0,444	18,51	0
3	6	0,101	0,187	2,94	20,20	14,55	31,55	0,540	21,50	0
3	7	0,125	0,187	4,28	25,00	17,12	31,44	0,668	25,29	0
3	8	0,150	0,187	3,88	20,00	19,40	30,67	0,802	28,66	0
3	9	0,180	0,189	4,20	17,70	23,73	36,39	0,952	35,05	1
3	10	0,170	0,197	4,00	17,00	23,53	42,48	0,863	34,76	2
3	11	0,155	0,192	9,20	25,30	36,36	-219,10	0,807	53,72	2
4	1	0,035	0,167	0,98	15,80	6,20	24,92	0,210	9,16	0
4	2	0,055	0,167	1,68	17,80	9,44	29,93	0,329	13,94	0
4	3	0,080	0,167	1,92	15,40	12,47	28,55	0,479	18,42	0
4	4	0,120	0,167	2,25	13,00	17,31	28,91	0,719	25,57	0
4	5	0,154	0,167	3,25	16,00	20,31	27,29	0,922	30,01	0
4	6	0,164	0,167	3,68	16,00	23,00	32,11	0,982	33,98	1
4	7	0,160	0,172	3,60	14,80	24,32	40,44	0,930	35,93	2
5	1	0,032	0,169	0,88	15,50	5,68	25,25	0,189	8,39	0
5	2	0,082	0,169	1,76	14,00	12,57	28,45	0,485	18,57	0
5	3	0,105	0,169	2,84	18,50	15,35	28,56	0,621	22,68	0
5	4	0,146	0,169	3,57	17,80	20,06	29,33	0,864	29,63	0
5	5	0,164	0,169	3,76	17,20	21,86	29,30	0,970	32,29	0
5	6	0,170	0,171	3,58	15,00	23,87	34,28	0,994	35,26	1
5	7	0,167	0,173	3,61	15,20	23,75	35,63	0,965	35,08	2
6	1	0,071	0,152	1,88	15,00	12,53	29,76	0,467	18,51	0
6	2	0,112	0,152	2,60	14,20	18,31	31,04	0,737	27,05	0
6	3	0,143	0,152	3,70	16,80	22,02	31,25	0,941	32,53	0
6	4	0,152	0,154	3,27	14,00	23,36	32,98	0,987	34,50	1
6	5	0,155	0,158	3,12	13,00	24,00	35,55	0,981	35,45	2
7	1	0,045	0,160	1,54	18,40	8,37	30,50	0,281	12,36	0
7	2	0,115	0,160	2,97	16,20	18,33	32,29	0,719	27,08	0
7	3	0,153	0,160	3,36	14,90	22,55	32,07	0,956	33,31	0
7	4	0,160	0,164	3,12	13,20	23,64	34,58	0,976	34,92	1
7	5	0,158	0,168	3,70	14,60	25,34	44,41	0,940	37,44	2
8	1	0,050	0,151	1,42	17,00	8,35	25,02	0,331	12,34	0
8	2	0,110	0,151	2,84	16,50	17,21	28,07	0,728	25,43	0
8	3	0,148	0,151	3,47	15,40	22,53	30,77	0,980	33,29	1
8	4	0,146	0,150	3,42	14,20	24,08	36,35	0,973	35,58	2
9	1	0,085	0,142	3,23	23,80	13,57	24,49	0,599	20,05	0
9	2	0,122	0,142	3,00	16,20	18,52	25,41	0,859	27,36	0
9	3	0,139	0,142	3,14	15,30	20,52	25,52	0,979	30,32	0
9	4	0,142	0,142	3,28	15,60	21,03	25,91	1,000	31,06	1

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Table B.1 – *Continued from previous page*

test	***measure***	***dh***	***L***	***dV***	***dt***	***Q***	***K***	***J***	***Re***	***failure***
		[m]	*[m]*	*10^{-3} [m^3]*	*[s]*	*10^{-5} [m^3/s]*	*10^{-3} [m/s]*	*[-]*	*[-]*	
9	5	0,140	0,144	3,05	13,80	22,10	29,90	0,972	32,65	2
9	6	0,138	0,147	3,50	15,20	23,03	34,68	0,939	34,01	2
9	7	0,133	0,150	3,78	15,20	24,87	47,19	0,887	36,74	2
10	1	0,068	0,150	2,61	23,00	11,35	26,46	0,453	16,76	0
10	2	0,097	0,150	3,00	20,20	14,85	25,59	0,647	21,94	0
10	3	0,114	0,150	3,96	23,10	17,14	26,27	0,760	25,32	0
10	4	0,124	0,150	3,20	17,30	18,50	26,78	0,827	27,32	0
10	5	0,142	0,150	3,20	15,53	20,61	27,00	0,947	30,44	0
10	6	0,149	0,151	2,92	13,30	21,95	28,82	0,987	32,43	1
10	7	0,151	0,153	3,50	15,33	22,83	31,33	0,987	33,73	2
10	8	0,134	0,159	3,65	13,77	26,51	65,73	0,843	39,16	2
11	1	0,068	0,134	2,94	24,10	12,20	25,62	0,507	18,02	0
11	2	0,105	0,134	3,10	17,80	17,42	25,89	0,784	25,73	0
11	3	0,125	0,134	3,44	17,10	20,12	26,34	0,933	29,72	0
11	4	0,133	0,134	3,20	14,80	21,62	27,68	0,993	31,94	1
11	5	0,128	0,137	3,16	13,80	22,90	34,51	0,934	33,83	2
11	6	0,126	0,139	3,42	14,30	23,92	40,53	0,906	35,33	2
11	7	0,123	0,142	3,46	13,80	25,07	50,75	0,866	37,04	2
12	1	0,081	0,136	2,86	19,30	14,82	28,47	0,596	21,89	0
12	2	0,112	0,136	2,90	15,30	18,95	28,19	0,824	28,00	0
12	3	0,136	0,138	3,46	15,30	22,61	30,75	0,986	33,41	1
12	4	0,128	0,141	3,44	14,60	23,56	38,89	0,908	34,81	2
12	5	0,122	0,144	3,27	13,20	24,77	51,16	0,847	36,59	2
12	6	0,121	0,147	3,66	13,80	26,52	69,93	0,823	39,18	2
13	1	0,072	0,130	2,75	19,50	14,10	28,86	0,554	20,83	0
13	2	0,110	0,130	3,26	16,60	19,64	29,01	0,846	29,01	0
13	3	0,127	0,130	3,28	14,90	22,01	29,43	0,977	32,52	1
13	4	0,129	0,132	3,48	15,30	22,75	31,56	0,977	33,60	2
13	5	0,129	0,135	3,22	13,60	23,68	35,98	0,956	34,98	2
13	6	0,118	0,137	3,90	15,60	25,00	50,88	0,861	36,93	2
14	1	0,070	0,144	2,64	19,70	13,40	31,56	0,486	19,80	0
14	2	0,111	0,144	3,26	17,40	18,74	30,37	0,771	27,68	0
14	3	0,136	0,144	3,08	14,00	22,00	30,99	0,944	32,50	0
14	4	0,141	0,144	3,30	14,40	22,92	32,00	0,979	33,85	1
14	5	0,137	0,146	2,98	12,40	24,03	38,56	0,938	35,50	2
14	6	0,128	0,149	3,60	14,60	24,66	49,01	0,859	36,42	2
14	7	0,125	0,153	3,06	12,00	25,50	61,12	0,817	37,67	2
15	1	0,092	0,135	3,30	21,20	15,57	25,80	0,681	22,99	0
15	2	0,118	0,135	3,27	17,00	19,24	26,59	0,874	28,41	0
15	3	0,132	0,135	3,26	15,60	20,90	26,46	0,978	30,87	0

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Table B.1 – *Continued from previous page*

test	***measure***	***dh*** *[m]*	***L*** *[m]*	***dV*** *10^{-3} [m^3]*	***dt*** *[s]*	***Q*** *10^{-5} [m^3/s]*	***K*** *10^{-3} [m/s]*	***J*** *[-]*	***Re*** *[-]*	***failure***
15	4	0,136	0,135	3,16	14,50	21,79	27,50	1,007	32,19	1
15	5	0,134	0,137	2,88	12,40	23,23	33,05	0,978	34,31	2
15	6	0,131	0,140	3,34	13,80	24,20	39,48	0,936	35,75	2
15	7	0,122	0,145	3,28	12,40	26,45	65,46	0,841	39,07	2
16	1	0,077	0,133	3,22	23,40	13,76	26,14	0,579	20,33	0
16	2	0,116	0,133	3,55	18,90	18,78	25,53	0,872	27,75	0
16	3	0,132	0,133	3,60	16,70	21,56	27,52	0,992	31,84	1
16	4	0,129	0,135	3,61	16,10	22,42	31,71	0,956	33,12	2
16	5	0,125	0,140	3,66	15,60	23,46	39,62	0,893	34,66	2
16	6	0,122	0,144	3,70	15,50	23,87	45,77	0,847	35,26	2
17	1	0,066	0,128	3,26	26,00	12,54	26,20	0,516	18,52	0
17	2	0,112	0,128	3,32	17,80	18,65	25,09	0,875	27,55	0
17	3	0,120	0,128	3,06	15,50	19,74	25,25	0,938	29,16	0
17	4	0,126	0,128	3,24	16,00	20,25	24,69	0,984	29,91	1
17	5	0,122	0,130	3,22	14,70	21,90	31,01	0,938	32,36	2
17	6	0,120	0,133	3,65	15,50	23,55	39,26	0,902	34,79	2
17	7	0,119	0,137	3,76	14,80	25,41	52,64	0,869	37,53	2
18	1	0,070	0,126	3,50	26,40	13,26	25,98	0,556	19,58	0
18	2	0,105	0,126	3,42	18,90	18,10	25,44	0,833	26,73	0
18	3	0,116	0,126	3,62	18,50	19,57	25,49	0,921	28,91	0
18	4	0,124	0,126	3,41	16,70	20,42	25,08	0,984	30,16	0
18	5	0,127	0,128	3,90	17,60	22,16	29,13	0,992	32,73	1
18	6	0,122	0,131	3,36	14,20	23,66	37,57	0,931	34,95	2
18	7	0,111	0,137	3,72	14,50	25,66	63,76	0,810	37,90	2
19	1	0,069	0,135	4,02	35,40	11,36	22,83	0,511	16,78	0
19	2	0,109	0,135	4,68	26,30	17,79	25,81	0,807	26,29	0
19	3	0,125	0,135	4,64	22,80	20,35	27,23	0,926	30,06	0
19	4	0,132	0,135	4,18	19,30	21,66	28,41	0,978	31,99	0
19	5	0,136	0,138	4,96	21,30	23,29	32,84	0,986	34,40	1
19	6	0,130	0,141	4,75	19,20	24,74	43,07	0,922	36,55	2
19	7	0,120	0,147	4,55	16,80	27,08	78,37	0,816	40,01	2
20	1	0,071	0,127	4,48	29,20	15,34	33,08	0,559	22,66	0
20	2	0,108	0,127	4,60	21,80	21,10	33,43	0,850	31,17	0
20	3	0,124	0,127	4,74	19,70	24,06	36,07	0,976	35,54	1
20	4	0,117	0,130	4,40	17,30	25,43	49,04	0,900	37,57	2
20	5	0,112	0,132	4,45	16,80	26,49	64,46	0,848	39,13	2
20	6	0,110	0,138	4,62	15,80	29,24	133,27	0,797	43,19	2
21	1	0,082	0,126	2,97	20,00	14,85	25,37	0,651	21,94	0
21	2	0,092	0,126	3,21	18,59	17,27	28,14	0,730	25,51	0
21	3	0,105	0,126	3,54	18,47	19,17	28,30	0,833	28,31	0

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Table B.1 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
21	4	0,111	0,126	4,02	19,59	20,52	29,82	0,881	30,31	0
21	5	0,118	0,126	4,07	18,41	22,11	31,74	0,937	32,66	0
21	6	0,126	0,126	4,26	18,22	23,38	32,35	1,000	34,54	1
21	7	0,123	0,130	3,86	15,82	24,40	39,53	0,946	36,04	2
21	8	0,121	0,134	4,35	16,88	25,77	50,77	0,903	38,07	2
22	1	0,067	0,128	4,00	29,78	13,43	28,69	0,523	19,84	0
22	2	0,088	0,128	4,00	24,44	16,37	27,80	0,688	24,18	0
22	3	0,102	0,128	3,72	20,00	18,60	28,52	0,797	27,48	0
22	4	0,115	0,128	3,76	18,59	20,23	28,13	0,898	29,88	0
22	5	0,120	0,128	3,89	18,47	21,06	28,61	0,938	31,11	0
22	6	0,125	0,128	4,22	19,59	21,54	28,16	0,977	31,82	0
22	7	0,129	0,130	4,07	18,41	22,11	28,98	0,992	32,66	1
22	8	0,126	0,132	4,26	18,22	23,38	34,97	0,955	34,54	2
22	9	0,123	0,134	3,86	15,82	24,40	41,80	0,918	36,04	2
22	10	0,121	0,137	4,35	16,88	25,77	53,24	0,883	38,07	2
23	1	0,096	0,126	3,19	21,65	14,73	20,46	0,762	21,77	0
23	2	0,118	0,126	3,45	16,75	20,60	27,41	0,937	30,43	0
23	3	0,125	0,126	4,11	18,88	21,74	28,02	0,992	32,12	0
23	4	0,129	0,129	3,50	15,59	22,45	29,58	1,000	33,16	1
23	5	0,124	0,133	3,94	16,25	24,25	39,93	0,932	35,82	2
23	6	0,120	0,134	4,74	18,34	25,85	52,17	0,896	38,18	2
23	7	0,116	0,137	3,76	14,03	26,80	67,90	0,847	39,59	2
24	1	0,091	0,133	3,14	19,87	15,80	26,33	0,684	23,34	0
24	2	0,108	0,133	3,64	20,06	18,15	26,52	0,812	26,80	0
24	3	0,119	0,133	4,00	20,75	19,28	25,82	0,895	28,48	0
24	4	0,129	0,133	4,28	20,62	20,76	26,43	0,970	30,66	0
24	5	0,133	0,133	4,00	18,94	21,12	26,13	1,000	31,20	0
24	6	0,136	0,135	4,06	18,34	22,14	28,40	1,007	32,70	1
24	7	0,132	0,137	3,60	15,37	23,42	34,56	0,964	34,60	2
24	8	0,126	0,141	3,72	14,81	25,12	47,88	0,894	37,11	2
25	1	0,083	0,122	3,44	21,28	16,17	27,60	0,680	23,88	0
25	2	0,100	0,122	3,64	19,72	18,46	27,00	0,820	27,27	0
25	3	0,112	0,122	4,01	20,00	20,05	26,79	0,918	29,62	0
25	4	0,121	0,122	3,68	17,06	21,57	27,58	0,992	31,87	1
25	5	0,122	0,124	3,58	15,65	22,88	31,62	0,984	33,79	2
25	6	0,117	0,127	4,15	17,69	23,46	37,48	0,921	34,65	2
25	7	0,105	0,132	3,61	14,15	25,51	65,24	0,795	37,69	2
26	1	0,096	0,140	3,15	19,72	15,97	26,74	0,686	23,60	0
26	2	0,112	0,140	3,30	18,15	18,18	27,18	0,800	26,86	0
26	3	0,122	0,140	3,80	19,69	19,30	26,87	0,871	28,51	0

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Table B.1 – *Continued from previous page*

test	***measure***	***dh***	***L***	***dV***	***dt***	***Q***	***K***	***J***	***Re***	***failure***
		[m]	*[m]*	*10^{-3} [m^3]*	*[s]*	*10^{-5} [m^3/s]*	*10^{-3} [m/s]*	*[-]*	*[-]*	
26	4	0,132	0,140	3,68	17,75	20,73	27,49	0,943	30,63	0
26	5	0,141	0,142	4,23	18,97	22,30	29,48	0,993	32,94	1
26	6	0,132	0,145	4,23	18,97	22,30	33,88	0,910	32,94	2
26	7	0,134	0,148	4,56	18,31	24,90	45,47	0,905	36,79	2
27	1	0,097	0,127	3,68	20,19	18,23	29,19	0,764	26,93	0
27	2	0,115	0,127	4,06	19,69	20,62	28,89	0,906	30,46	0
27	3	0,123	0,127	3,46	15,94	21,71	28,96	0,969	32,07	0
27	4	0,127	0,127	4,46	19,84	22,48	29,66	1,000	33,21	1
27	5	0,128	0,129	3,62	15,56	23,26	32,40	0,992	34,37	2
27	6	0,124	0,131	3,75	15,34	24,45	39,69	0,947	36,11	2
27	7	0,121	0,137	3,84	14,71	26,10	55,63	0,883	38,56	2
28	1	0,091	0,122	2,98	16,88	17,65	28,44	0,746	26,08	0
28	2	0,113	0,122	3,62	17,34	20,88	28,63	0,926	30,84	0
28	3	0,119	0,122	3,65	16,66	21,91	29,21	0,975	32,36	0
28	4	0,124	0,124	3,44	15,47	22,24	28,99	1,000	32,85	1
28	5	0,122	0,127	3,66	15,65	23,39	34,61	0,961	34,55	2
28	6	0,121	0,131	3,73	15,00	24,87	43,55	0,924	36,73	2
29	1	0,093	0,124	3,34	18,90	17,67	28,27	0,750	26,11	0
29	2	0,104	0,124	3,65	18,94	19,27	28,33	0,839	28,47	0
29	3	0,116	0,124	3,60	17,28	20,83	28,08	0,935	30,78	0
29	4	0,121	0,124	3,61	16,72	21,59	28,32	0,976	31,89	1
29	5	0,124	0,126	3,57	16,15	22,11	29,35	0,984	32,65	2
29	6	0,123	0,128	3,50	15,10	23,18	33,87	0,961	34,24	2
29	7	0,120	0,132	3,76	15,50	24,26	41,89	0,909	35,83	2
30	1	0,085	0,118	3,35	19,31	17,35	28,94	0,720	25,63	0
30	2	0,098	0,118	3,58	18,69	19,15	28,41	0,831	28,30	0
30	3	0,110	0,118	3,60	17,16	20,98	28,63	0,932	30,99	0
30	4	0,115	0,118	3,96	18,16	21,81	28,96	0,975	32,21	0
30	5	0,117	0,120	3,39	15,34	22,10	29,76	0,975	32,65	1
30	6	0,117	0,122	4,26	18,03	23,63	35,58	0,959	34,90	2
30	7	0,112	0,128	4,12	15,62	26,38	58,95	0,875	38,96	2

B.2 Sample B measurements

All measurements were performed with a cylinder with a flow area of 0.01188 m^2 and water with a temperature of 16 ℃.

Table B.2: Measurements of sample B

test	*measure*	*dh* [m]	*L* [m]	*dV* 10^{-3} [m^3]	*dt* [s]	*Q* 10^{-5} [m^3/s]	*K* 10^{-3} [m/s]	*J* [-]	*Re* [-]	*failure*
1	2	0,062	0,135	1,91	13,90	13,74	25,19	0,459	20,30	0
1	3	0,099	0,135	3,20	16,20	19,75	22,68	0,733	29,18	0
1	4	0,130	0,140	3,40	12,80	26,56	24,09	0,929	39,24	1
1	5	0,116	0,140	3,54	13,00	27,23	27,67	0,829	40,23	2
1	6	0,116	0,143	3,26	12,00	27,17	28,20	0,811	40,13	2
2	1	0,066	0,146	2,58	18,10	14,25	26,55	0,452	21,06	0
2	2	0,110	0,146	3,19	16,40	19,45	21,74	0,753	28,73	0
2	3	0,136	0,146	3,15	13,00	24,23	21,90	0,932	35,79	0
2	4	0,141	0,146	3,15	11,50	27,39	23,88	0,966	40,46	1
2	5	0,127	0,151	3,30	12,40	26,61	26,64	0,841	39,31	2
2	6	0,125	0,153	3,57	13,20	27,05	27,87	0,817	39,95	2
3	1	0,068	0,142	2,38	16,60	14,34	25,21	0,479	21,18	0
3	2	0,103	0,142	2,63	13,50	19,48	22,61	0,725	28,78	0
3	3	0,138	0,142	3,34	13,60	24,56	21,28	0,972	36,28	0
3	4	0,140	0,144	2,92	11,50	25,39	21,99	0,972	37,51	1
3	5	0,125	0,149	3,28	12,40	26,45	26,55	0,839	39,07	2
3	6	0,124	0,151	3,82	14,00	27,29	27,98	0,821	40,31	2
4	1	0,082	0,149	3,12	19,60	15,92	24,36	0,550	23,51	0
4	2	0,107	0,149	3,06	15,70	19,49	22,85	0,718	28,79	0
4	3	0,118	0,149	3,74	18,20	20,55	21,85	0,792	30,36	0
4	4	0,138	0,149	4,80	21,10	22,75	20,68	0,926	33,61	0
4	5	0,146	0,150	3,50	14,20	24,65	21,32	0,973	36,41	1
4	6	0,137	0,152	3,30	12,80	25,78	24,09	0,901	38,08	2
4	7	0,138	0,156	3,61	13,60	26,54	25,27	0,885	39,21	2
4	8	0,131	0,159	3,85	13,60	28,31	28,93	0,824	41,82	2
5	1	0,054	0,136	2,28	24,40	9,34	19,82	0,397	13,80	0
5	2	0,101	0,136	2,97	15,80	18,80	21,31	0,743	27,77	0
5	3	0,125	0,136	3,08	13,50	22,81	20,90	0,919	33,70	0
5	4	0,134	0,136	3,87	15,70	24,65	21,07	0,985	36,41	1
5	5	0,134	0,138	3,24	12,90	25,12	21,78	0,971	37,10	2
5	6	0,118	0,143	4,20	15,60	26,92	27,47	0,825	39,77	2
5	7	0,116	0,146	3,70	12,70	29,13	30,88	0,795	43,04	2
6	1	0,071	0,135	3,37	22,70	14,85	23,77	0,526	21,93	0
6	2	0,096	0,135	3,02	15,90	18,99	22,49	0,711	28,06	0
6	3	0,130	0,136	3,56	14,70	24,22	21,33	0,956	35,77	0

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Table B.2 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
6	4	0,135	0,138	3,54	13,90	25,47	21,92	0,978	37,62	1
6	5	0,120	0,145	3,30	12,10	27,27	27,75	0,828	40,29	2
6	6	0,119	0,145	4,01	14,50	27,66	28,37	0,821	40,85	2
7	1	0,075	0,140	2,98	21,10	14,12	22,20	0,536	20,86	0
7	2	0,120	0,140	3,40	15,80	21,52	21,14	0,857	31,79	0
7	3	0,132	0,140	3,46	14,40	24,03	21,46	0,943	35,49	0
7	4	0,136	0,140	3,67	15,00	24,47	21,21	0,971	36,14	1
7	5	0,136	0,142	3,36	13,20	25,45	22,38	0,958	37,60	2
7	6	0,124	0,148	3,76	14,00	26,86	26,99	0,838	39,67	2
8	1	0,076	0,135	2,86	20,20	14,16	21,18	0,563	20,92	0
8	2	0,117	0,135	3,16	14,60	21,64	21,03	0,867	31,97	0
8	3	0,124	0,135	3,32	14,50	22,90	20,99	0,919	33,82	0
8	4	0,132	0,135	3,42	14,00	24,43	21,04	0,978	36,09	1
8	5	0,134	0,137	3,74	14,60	25,62	22,05	0,978	37,84	2
8	6	0,117	0,142	3,93	14,80	26,55	27,14	0,824	39,23	2
8	7	0,115	0,144	3,80	13,70	27,74	29,24	0,799	40,97	2
9	1	0,082	0,146	3,01	19,70	15,28	22,91	0,562	22,57	0
9	2	0,109	0,146	3,34	16,90	19,76	22,29	0,747	29,19	0
9	3	0,136	0,146	3,63	15,30	23,73	21,45	0,932	35,05	0
9	4	0,143	0,146	3,52	13,60	25,88	22,25	0,979	38,23	1
9	5	0,128	0,153	4,01	14,70	27,28	27,46	0,837	40,30	2
9	6	0,126	0,156	3,94	13,80	28,55	29,76	0,808	42,18	2
10	1	0,085	0,139	2,92	18,00	16,22	22,34	0,612	23,96	0
10	2	0,122	0,139	3,46	15,60	22,18	21,28	0,878	32,76	0
10	3	0,136	0,139	3,82	15,60	24,49	21,07	0,978	36,17	1
10	4	0,138	0,141	3,44	13,50	25,48	21,92	0,979	37,64	2
10	5	0,123	0,144	3,32	12,40	26,77	26,39	0,854	39,55	2
10	6	0,123	0,147	3,82	13,80	27,68	27,86	0,837	40,89	2
10	7	0,122	0,149	3,96	13,80	28,70	29,51	0,819	42,39	2
11	1	0,069	0,132	4,60	34,10	13,49	21,73	0,523	19,93	0
11	2	0,115	0,132	4,85	22,30	21,75	21,02	0,871	32,13	0
11	3	0,132	0,132	5,10	20,30	25,12	21,15	1,000	37,11	1
11	4	0,133	0,134	4,46	17,20	25,93	22,00	0,993	38,30	2
11	5	0,118	0,138	4,46	16,40	27,20	26,78	0,855	40,17	2
11	6	0,116	0,142	4,23	14,80	28,58	29,46	0,817	42,22	2
12	1	0,078	0,145	4,40	27,20	16,18	25,32	0,538	23,90	0
12	2	0,106	0,145	4,22	20,80	20,29	23,37	0,731	29,97	0
12	3	0,136	0,145	4,32	17,10	25,26	22,68	0,938	37,32	0
12	4	0,142	0,145	4,85	18,30	26,50	22,79	0,979	39,15	1
12	5	0,132	0,149	4,15	15,10	27,48	26,12	0,886	40,60	2

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Table B.2 – *Continued from previous page*

test	***measure***	***dh*** *[m]*	***L*** *[m]*	***dV*** *10-3 [m3]*	***dt*** *[s]*	***Q*** *10-5 [m3/s]*	***K*** *10-3 [m/s]*	***J*** *[-]*	***Re*** *[-]*	***failure***
12	6	0,129	0,150	4,31	14,90	28,93	28,32	0,860	42,73	2
12	7	0,126	0,155	3,87	13,50	28,67	29,69	0,813	42,35	2
13	1	0,085	0,139	4,89	29,50	16,58	22,82	0,612	24,49	0
13	2	0,102	0,139	4,72	23,10	20,43	23,45	0,734	30,18	0
13	3	0,131	0,139	4,20	16,60	25,30	22,61	0,942	37,38	0
13	4	0,137	0,139	4,95	17,90	27,65	23,62	0,986	40,85	1
13	5	0,122	0,143	4,48	16,80	26,67	26,32	0,853	39,39	2
13	6	0,119	0,149	4,54	15,00	30,27	31,91	0,799	44,71	2
14	1	0,075	0,140	4,54	29,70	15,29	24,03	0,536	22,58	0
14	2	0,095	0,140	4,98	28,20	17,66	21,91	0,679	26,09	0
14	3	0,117	0,140	5,12	22,90	22,36	22,53	0,836	33,03	0
14	4	0,128	0,140	4,98	19,90	25,03	23,05	0,914	36,97	0
14	5	0,134	0,142	5,05	19,10	26,44	23,59	0,944	39,06	1
14	6	0,122	0,146	5,24	18,90	27,72	27,94	0,836	40,96	2
14	7	0,119	0,148	5,24	17,90	29,27	30,66	0,804	43,24	2
15	1	0,070	0,130	5,03	32,80	15,34	23,98	0,538	22,65	0
15	2	0,102	0,130	5,44	28,40	19,15	20,56	0,785	28,30	0
15	3	0,118	0,130	5,47	24,60	22,24	20,63	0,908	32,85	0
15	4	0,127	0,130	5,02	20,80	24,13	20,80	0,977	35,65	1
15	5	0,113	0,132	5,52	22,30	24,75	24,35	0,856	36,57	2
15	6	0,112	0,134	4,74	17,30	27,40	27,60	0,836	40,47	2
15	7	0,110	0,137	5,26	17,20	30,58	32,07	0,803	45,18	2
16	1	0,074	0,140	4,50	29,40	15,31	24,38	0,529	22,61	0
16	2	0,101	0,140	4,80	23,00	20,87	24,36	0,721	30,83	0
16	3	0,134	0,140	4,94	18,60	26,56	23,36	0,957	39,23	1
16	4	0,121	0,143	5,34	19,40	27,53	27,39	0,846	40,66	2
16	5	0,120	0,145	5,22	18,60	28,06	28,55	0,828	41,46	2
16	6	0,119	0,147	5,50	19,00	28,95	30,11	0,810	42,76	2
17	1	0,081	0,143	4,94	31,10	15,88	23,61	0,566	23,46	0
17	2	0,116	0,143	4,92	23,60	20,85	21,64	0,811	30,80	0
17	3	0,138	0,143	5,45	21,50	25,35	22,12	0,965	37,45	1
17	4	0,140	0,145	4,49	18,20	24,67	21,51	0,966	36,44	2
17	5	0,132	0,149	5,23	19,50	26,82	25,49	0,886	39,62	2
17	6	0,128	0,153	5,20	18,00	28,89	29,08	0,837	42,68	2
18	1	0,073	0,133	4,18	26,00	16,08	24,66	0,549	23,75	0
18	2	0,112	0,133	4,97	22,90	21,70	21,70	0,842	32,06	0
18	3	0,124	0,133	4,92	20,60	23,88	21,57	0,932	35,28	0
18	4	0,130	0,133	5,16	20,30	25,42	21,90	0,977	37,55	1
18	5	0,120	0,138	5,87	21,80	26,93	26,07	0,870	39,78	2
18	6	0,116	0,143	4,92	17,20	28,60	29,69	0,811	42,26	2

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Table B.2 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
19	1	0,071	0,126	5,50	34,70	15,85	23,68	0,563	23,41	0
19	2	0,104	0,126	4,66	22,60	20,62	21,03	0,825	30,46	0
19	3	0,121	0,126	4,82	20,60	23,40	20,52	0,960	34,56	0
19	4	0,126	0,128	5,32	20,20	26,34	22,53	0,984	38,91	1
19	5	0,115	0,131	5,22	19,90	26,23	25,16	0,878	38,75	2
19	6	0,112	0,135	4,41	15,80	27,91	28,33	0,830	41,23	2
20	1	0,081	0,134	4,80	35,60	13,48	18,78	0,604	19,92	0
20	2	0,112	0,134	4,70	25,10	18,73	18,86	0,836	27,66	0
20	3	0,127	0,134	5,23	23,40	22,35	19,86	0,948	33,02	0
20	4	0,131	0,136	5,20	21,90	23,74	20,76	0,963	35,08	1
20	5	0,126	0,139	4,65	18,50	25,14	23,35	0,906	37,13	2
20	6	0,117	0,143	4,86	18,00	27,00	27,79	0,818	39,88	2
21	1	0,078	0,124	3,10	18,74	16,54	22,14	0,629	24,44	0
21	2	0,094	0,124	3,45	18,65	18,50	20,55	0,758	27,33	0
21	3	0,109	0,124	3,82	17,15	22,27	21,34	0,879	32,90	0
21	4	0,112	0,124	3,54	16,02	22,10	20,60	0,903	32,64	0
21	5	0,121	0,126	3,43	13,66	25,11	22,02	0,960	37,09	1
21	6	0,112	0,129	3,92	15,14	25,89	25,11	0,868	38,25	2
21	7	0,102	0,133	3,98	16,64	23,92	26,26	0,767	35,33	2
22	1	0,077	0,123	2,88	16,74	17,20	23,14	0,626	25,41	0
22	2	0,098	0,123	2,94	14,75	19,93	21,06	0,797	29,44	0
22	3	0,110	0,123	3,42	15,35	22,28	20,98	0,894	32,91	0
22	4	0,115	0,123	3,78	16,25	23,26	20,95	0,935	34,36	0
22	5	0,119	0,125	3,26	13,16	24,77	21,91	0,952	36,59	1
22	6	0,111	0,129	3,67	13,84	26,52	25,95	0,860	39,17	2
22	7	0,108	0,133	3,66	13,64	26,83	27,82	0,812	39,64	2
23	1	0,067	0,117	2,99	17,74	16,85	24,78	0,573	24,90	0
23	2	0,088	0,117	3,22	15,65	20,58	23,03	0,752	30,39	0
23	3	0,102	0,117	3,72	16,15	23,03	22,25	0,872	34,03	0
23	4	0,108	0,119	3,66	15,15	24,16	22,41	0,908	35,69	0
23	5	0,114	0,119	3,48	12,66	27,49	24,16	0,958	40,61	1
23	6	0,108	0,121	3,87	13,14	29,45	27,78	0,893	43,51	2
23	7	0,102	0,125	4,06	14,64	27,73	28,62	0,816	40,97	2
24	1	0,076	0,127	3,00	18,58	16,15	22,72	0,598	23,85	0
24	2	0,092	0,127	3,14	16,63	18,88	21,95	0,724	27,89	0
24	3	0,111	0,127	3,62	16,69	21,69	20,90	0,874	32,04	0
24	4	0,117	0,127	3,48	15,45	22,52	20,59	0,921	33,27	0
24	5	0,124	0,128	3,66	15,20	24,08	20,93	0,969	35,57	1
24	6	0,122	0,131	4,00	15,69	25,49	23,05	0,931	37,66	2
24	7	0,118	0,134	3,90	14,43	27,03	25,84	0,881	39,92	2

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Table B.2 – *Continued from previous page*

test	***measure***	***dh***	***L***	***dV***	***dt***	***Q***	***K***	***J***	***Re***	***failure***
		[m]	*[m]*	*10^{-3} [m^3]*	*[s]*	*10^{-5} [m^3/s]*	*10^{-3} [m/s]*	*[-]*	*[-]*	
25	1	0,080	0,122	3,28	17,91	18,31	23,52	0,656	27,05	0
25	2	0,098	0,122	3,38	15,77	21,43	22,47	0,803	31,66	0
25	3	0,109	0,122	3,69	15,76	23,41	22,07	0,893	34,59	0
25	4	0,116	0,122	3,88	15,85	24,48	21,68	0,951	36,16	1
25	5	0,115	0,125	3,68	13,44	27,38	25,06	0,920	40,45	2
25	6	0,110	0,130	3,74	13,88	26,95	26,81	0,846	39,80	2
26	1	0,078	0,121	3,00	16,49	18,19	23,76	0,645	26,87	0
26	2	0,089	0,121	3,16	16,44	19,22	22,00	0,736	28,39	0
26	3	0,102	0,121	3,12	14,43	21,62	21,60	0,843	31,94	0
26	4	0,108	0,121	3,58	15,58	22,98	21,68	0,893	33,94	0
26	5	0,116	0,121	3,38	13,90	24,32	21,36	0,959	35,92	1
26	6	0,115	0,123	3,44	13,64	25,22	22,71	0,935	37,26	2
26	7	0,106	0,129	4,73	17,13	27,61	28,29	0,822	40,79	2
27	1	0,081	0,138	3,92	21,27	18,43	26,44	0,587	27,22	0
27	2	0,101	0,138	4,39	20,03	21,92	25,22	0,732	32,38	0
27	3	0,111	0,138	4,76	20,64	23,06	24,14	0,804	34,07	0
27	4	0,119	0,138	4,84	19,76	24,49	23,92	0,862	36,18	0
27	5	0,124	0,138	4,63	18,44	25,11	23,53	0,899	37,09	0
27	6	0,128	0,139	4,65	17,93	25,93	23,71	0,921	38,31	0
27	7	0,131	0,140	4,45	16,68	26,68	24,01	0,936	39,41	1
27	8	0,122	0,142	5,06	18,59	27,22	26,68	0,859	40,21	2
27	9	0,122	0,144	4,72	16,89	27,95	27,77	0,847	41,28	2
27	10	0,121	0,146	4,84	14,43	33,54	34,08	0,829	49,55	2
28	1	0,074	0,122	3,60	20,03	17,97	24,95	0,607	26,55	0
28	2	0,086	0,122	4,22	21,53	19,60	23,41	0,705	28,95	0
28	3	0,095	0,122	4,27	20,26	21,08	22,79	0,779	31,13	0
28	4	0,104	0,122	3,60	16,19	22,24	21,96	0,852	32,85	0
28	5	0,108	0,122	4,42	18,86	23,44	22,29	0,885	34,62	0
28	6	0,113	0,122	3,89	16,32	23,84	21,67	0,926	35,21	0
28	7	0,116	0,122	4,00	16,36	24,45	21,65	0,951	36,12	0
28	8	0,120	0,123	4,17	16,26	25,65	22,13	0,976	37,88	1
28	9	0,119	0,125	3,88	14,76	26,29	23,25	0,952	38,83	2
28	10	0,110	0,129	4,12	15,04	27,39	27,05	0,853	40,47	2
29	1	0,084	0,120	4,26	21,29	20,01	24,07	0,700	29,56	0
29	2	0,095	0,120	3,86	17,73	21,77	23,16	0,792	32,16	0
29	3	0,103	0,120	3,37	14,47	23,29	22,85	0,858	34,40	0
29	4	0,108	0,120	3,80	15,69	24,22	22,66	0,900	35,78	0
29	5	0,112	0,120	4,14	16,69	24,81	22,38	0,933	36,64	0
29	6	0,114	0,120	3,62	14,20	25,49	22,60	0,950	37,66	0
29	7	0,117	0,122	3,72	14,21	26,18	22,98	0,959	38,67	1

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Table B.2 – *Continued from previous page*

test	***measure***	***dh***	***L***	***dV***	***dt***	***Q***	***K***	***J***	***Re***	***failure***
		[m]	*[m]*	*10^{-3} [m^3]*	*[s]*	*10^{-5} [m^3/s]*	*10^{-3} [m/s]*	*[-]*	*[-]*	
29	8	0,110	0,123	3,78	14,10	26,81	25,24	0,894	39,60	2
29	9	0,107	0,126	3,72	13,20	28,18	27,94	0,849	41,63	2
30	1	0,085	0,120	3,36	16,18	20,77	24,69	0,708	30,68	0
30	2	0,098	0,120	3,61	16,05	22,49	23,19	0,817	33,23	0
30	3	0,107	0,120	3,68	15,06	24,44	23,07	0,892	36,10	0
30	4	0,111	0,121	3,76	14,97	25,12	23,05	0,917	37,10	0
30	5	0,115	0,122	3,68	14,14	26,03	23,25	0,943	38,45	1
30	6	0,110	0,124	3,62	13,43	26,95	25,58	0,887	39,82	2
30	7	0,106	0,126	3,87	13,95	27,74	27,77	0,841	40,98	2

B.3 Sample C measurements

All measurements were performed with a cylinder with a flow area of 0.01188 m^2 and water with a temperature of 16 ℃.

Table B.3: Measurements of sample C

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
1	2	0,103	0,137	3,51	52,40	6,70	7,50	0,752	4,95	0
1	3	0,113	0,137	3,61	43,90	8,22	8,39	0,825	6,07	0
1	4	0,116	0,137	4,02	42,18	9,53	9,48	0,847	7,04	1
1	5	0,114	0,143	4,18	43,54	9,60	10,14	0,797	7,09	2
1	6	0,117	0,147	4,42	35,24	12,54	13,27	0,796	9,26	2
2	1	0,082	0,122	3,28	72,96	4,50	5,63	0,672	3,32	0
2	2	0,087	0,122	3,10	62,16	4,99	5,89	0,713	3,68	0
2	3	0,095	0,122	3,22	52,81	6,10	6,59	0,779	4,50	0
2	4	0,099	0,122	3,74	53,81	6,95	7,21	0,811	5,13	0
2	5	0,105	0,125	3,69	43,10	8,56	8,58	0,840	6,32	1
2	6	0,103	0,127	3,82	43,81	8,72	9,05	0,811	6,44	2
3	1	0,060	0,116	2,34	70,44	3,32	5,41	0,517	2,45	0
3	2	0,071	0,116	3,03	61,20	4,95	6,81	0,612	3,66	0
3	3	0,079	0,116	3,25	57,85	5,62	6,95	0,681	4,15	0
3	4	0,088	0,116	3,48	52,85	6,58	7,31	0,759	4,86	0
3	5	0,095	0,118	3,22	40,15	8,02	8,39	0,805	5,92	0
3	6	0,099	0,121	3,92	42,85	9,15	9,41	0,818	6,76	1
4	1	0,070	0,123	2,90	77,30	3,75	5,55	0,569	2,77	0
4	2	0,080	0,123	2,96	69,55	4,26	5,51	0,650	3,14	0
4	3	0,089	0,123	3,06	65,11	4,70	5,47	0,724	3,47	0
4	4	0,098	0,123	3,15	60,51	5,21	5,50	0,797	3,85	0
4	5	0,107	0,123	3,26	57,62	5,66	5,48	0,870	4,18	0
4	6	0,113	0,125	3,46	54,22	6,38	5,94	0,904	4,71	1
4	7	0,108	0,128	3,93	47,20	8,33	8,31	0,844	6,15	2
4	8	0,103	0,131	3,93	47,20	8,33	8,92	0,786	6,15	2
5	1	0,075	0,123	2,90	71,42	4,06	5,61	0,610	3,00	0
5	2	0,094	0,123	3,40	67,40	5,04	5,56	0,764	3,73	0
5	3	0,104	0,123	3,65	64,10	5,69	5,67	0,846	4,21	0
5	4	0,111	0,123	3,36	54,37	6,18	5,77	0,902	4,56	1
5	5	0,109	0,125	3,26	51,21	6,37	6,15	0,872	4,70	2
5	6	0,101	0,128	4,12	48,13	8,56	9,13	0,789	6,32	2
5	7	0,101	0,133	3,54	35,98	9,84	10,91	0,759	7,27	2
6	1	0,073	0,132	2,70	73,02	3,70	5,63	0,553	2,73	0
6	2	0,086	0,132	3,00	67,79	4,43	5,72	0,652	3,27	0
6	3	0,097	0,132	3,33	67,48	4,93	5,65	0,735	3,64	0

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Table B.3 – *Continued from previous page*

test	***measure***	***dh***	***L***	***dV***	***dt***	***Q***	***K***	***J***	***Re***	***failure***
		[m]	*[m]*	*10^-3 [m^3]*	*[s]*	*10^-5 [m^3/s]*	*10^-3 [m/s]*	*[-]*	*[-]*	
6	4	0,108	0,132	3,32	58,63	5,66	5,83	0,818	4,18	0
6	5	0,118	0,132	3,46	55,48	6,24	5,87	0,894	4,61	1
6	6	0,118	0,134	3,50	45,54	7,69	7,35	0,881	5,68	2
6	7	0,115	0,138	3,24	42,41	7,64	7,72	0,833	5,64	2
6	8	0,110	0,140	3,88	46,54	8,34	8,93	0,786	6,16	2
7	1	0,063	0,113	2,88	77,10	3,74	5,64	0,558	2,76	0
7	2	0,080	0,113	3,37	69,47	4,85	5,77	0,708	3,58	0
7	3	0,085	0,113	3,45	65,12	5,30	5,94	0,752	3,92	0
7	4	0,095	0,113	3,83	55,32	6,92	6,93	0,841	5,11	0
7	5	0,102	0,113	3,87	47,53	8,15	7,60	0,903	6,02	1
7	6	0,103	0,117	3,69	42,20	8,73	8,35	0,880	6,45	2
7	7	0,102	0,122	4,02	43,49	9,24	9,31	0,836	6,83	2
8	1	0,066	0,117	3,08	81,22	3,79	5,66	0,564	2,80	0
8	2	0,080	0,117	3,12	67,14	4,65	5,72	0,684	3,43	0
8	3	0,095	0,117	3,28	59,00	5,56	5,77	0,812	4,11	0
8	4	0,104	0,117	3,16	50,63	6,24	5,91	0,889	4,61	0
8	5	0,108	0,119	3,22	49,74	6,47	6,01	0,908	4,78	1
8	6	0,099	0,122	3,98	50,88	7,82	8,12	0,811	5,78	2
8	7	0,098	0,125	3,70	42,15	8,78	9,43	0,784	6,48	2
9	1	0,072	0,122	1,60	43,43	3,68	5,26	0,590	2,72	0
9	2	0,082	0,122	1,64	39,19	4,18	5,24	0,672	3,09	0
9	3	0,100	0,122	1,68	33,32	5,04	5,18	0,820	3,72	0
9	4	0,114	0,122	1,82	31,69	5,74	5,18	0,934	4,24	1
9	5	0,102	0,128	2,24	27,66	8,10	8,56	0,797	5,98	2
9	6	0,105	0,132	2,18	22,46	9,71	10,27	0,795	7,17	2
10	1	0,061	0,106	1,55	40,82	3,80	5,56	0,575	2,80	0
10	2	0,073	0,106	1,59	34,65	4,59	5,61	0,689	3,39	0
10	3	0,089	0,106	1,77	32,21	5,50	5,51	0,840	4,06	0
10	4	0,099	0,106	1,62	26,22	6,18	5,57	0,934	4,56	1
10	5	0,093	0,111	1,83	23,72	7,72	7,75	0,838	5,70	2
10	6	0,092	0,119	1,83	18,59	9,84	10,72	0,773	7,27	2
11	1	0,066	0,109	1,58	39,29	4,02	5,59	0,606	2,97	0
11	2	0,077	0,109	1,77	37,22	4,76	5,67	0,706	3,51	0
11	3	0,089	0,109	1,72	31,62	5,44	5,61	0,817	4,02	0
11	4	0,099	0,109	1,76	28,56	6,16	5,71	0,908	4,55	1
11	5	0,101	0,111	1,78	27,72	6,42	5,94	0,910	4,74	2
11	6	0,091	0,115	1,72	22,12	7,78	8,27	0,791	5,74	2
11	7	0,089	0,115	1,78	19,29	9,23	10,04	0,774	6,82	2
12	1	0,059	0,113	1,66	51,60	3,22	5,19	0,522	2,38	0
12	2	0,076	0,113	1,65	40,03	4,12	5,16	0,673	3,04	0

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Table B.3 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
12	3	0,092	0,113	1,76	35,03	5,02	5,20	0,814	3,71	0
12	4	0,104	0,113	1,68	28,93	5,81	5,31	0,920	4,29	1
12	5	0,096	0,119	1,79	22,25	8,04	8,40	0,807	5,94	2
12	6	0,096	0,123	1,88	19,75	9,52	10,27	0,780	7,03	2
13	1	0,066	0,118	1,86	55,06	3,38	5,09	0,559	2,50	0
13	2	0,087	0,118	1,95	44,28	4,40	5,03	0,737	3,25	0
13	3	0,101	0,118	1,81	36,10	5,01	4,93	0,856	3,70	0
13	4	0,107	0,118	1,86	34,54	5,39	5,00	0,907	3,98	0
13	5	0,110	0,118	1,62	28,97	5,59	5,05	0,932	4,13	0
13	6	0,114	0,119	1,86	32,50	5,72	5,03	0,958	4,23	1
13	7	0,098	0,126	1,78	22,09	8,06	8,72	0,778	5,95	2
13	8	0,098	0,128	1,82	19,75	9,22	10,13	0,766	6,81	2
14	1	0,077	0,106	1,78	39,90	4,46	5,17	0,726	3,30	0
14	2	0,089	0,106	1,79	34,50	5,19	5,20	0,840	3,83	0
14	3	0,097	0,106	1,85	32,22	5,74	5,28	0,915	4,24	1
14	4	0,094	0,109	1,79	26,62	6,72	6,57	0,862	4,97	2
14	5	0,091	0,118	1,78	20,53	8,67	9,47	0,771	6,40	2
15	1	0,071	0,125	1,70	48,53	3,50	5,19	0,568	2,59	0
15	2	0,087	0,125	1,84	42,60	4,32	5,23	0,696	3,19	0
15	3	0,106	0,125	1,83	35,62	5,14	5,10	0,848	3,79	0
15	4	0,112	0,125	1,79	32,25	5,55	5,22	0,896	4,10	0
15	5	0,118	0,125	1,80	30,03	5,99	5,35	0,944	4,43	1
15	6	0,109	0,133	1,77	23,09	7,67	7,88	0,820	5,66	2
15	7	0,109	0,137	1,77	17,47	10,13	10,72	0,796	7,48	2
16	1	0,080	0,131	1,84	49,84	3,69	5,09	0,611	2,73	0
16	2	0,097	0,131	1,93	42,62	4,53	5,15	0,740	3,34	0
16	3	0,113	0,131	1,87	35,31	5,30	5,17	0,863	3,91	0
16	4	0,121	0,131	1,82	32,38	5,62	5,12	0,924	4,15	0
16	5	0,124	0,131	1,86	32,16	5,78	5,14	0,947	4,27	0
16	6	0,128	0,131	1,88	31,85	5,90	5,09	0,977	4,36	1
16	7	0,114	0,137	1,82	23,25	7,83	7,92	0,832	5,78	2
16	8	0,116	0,141	1,73	19,16	9,03	9,24	0,823	6,67	2
17	1	0,078	0,119	1,90	47,79	3,98	5,11	0,655	2,94	0
17	2	0,098	0,119	1,91	38,29	4,99	5,10	0,824	3,68	0
17	3	0,115	0,119	1,90	31,66	6,00	5,23	0,966	4,43	1
17	4	0,106	0,126	1,95	25,88	7,53	7,54	0,841	5,57	2
17	5	0,103	0,131	1,90	18,75	10,13	10,85	0,786	7,48	2
18	1	0,086	0,142	1,62	40,44	4,01	5,57	0,606	2,96	0
18	2	0,104	0,142	1,78	36,75	4,84	5,57	0,732	3,58	0
18	3	0,117	0,142	1,89	34,90	5,42	5,53	0,824	4,00	0

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Table B.3 – *Continued from previous page*

test	***measure***	***dh*** *[m]*	***L*** *[m]*	***dV*** *10^{-3} [m^3]*	***dt*** *[s]*	***Q*** *10^{-5} [m^3/s]*	***K*** *10^{-3} [m/s]*	***J*** *[-]*	***Re*** *[-]*	***failure***
18	4	0,124	0,142	1,76	30,47	5,78	5,57	0,873	4,27	0
18	5	0,131	0,145	1,74	26,85	6,48	6,04	0,903	4,79	1
18	6	0,121	0,150	1,87	22,87	8,18	8,53	0,807	6,04	2
18	7	0,120	0,152	1,85	21,28	8,69	9,27	0,789	6,42	2
18	8	0,120	0,154	1,90	19,88	9,56	10,33	0,779	7,06	2
19	1	0,080	0,127	1,76	43,31	4,06	5,43	0,630	3,00	0
19	2	0,098	0,127	1,76	36,10	4,88	5,32	0,772	3,60	0
19	3	0,106	0,127	1,80	34,19	5,26	5,31	0,835	3,89	0
19	4	0,112	0,127	1,78	31,85	5,59	5,34	0,882	4,13	0
19	5	0,114	0,129	1,87	31,93	5,86	5,58	0,884	4,33	0
19	6	0,116	0,129	1,91	31,94	5,98	5,60	0,899	4,42	1
19	7	0,112	0,131	1,82	25,28	7,20	7,09	0,855	5,32	2
19	8	0,110	0,134	1,83	22,29	8,21	8,42	0,821	6,06	2
19	9	0,111	0,137	1,85	20,41	9,06	9,42	0,810	6,69	2
20	1	0,070	0,127	1,78	50,06	3,56	5,43	0,551	2,63	0
20	2	0,088	0,127	1,82	41,47	4,39	5,33	0,693	3,24	0
20	3	0,104	0,127	1,80	34,94	5,15	5,30	0,819	3,81	0
20	4	0,111	0,127	1,84	33,50	5,49	5,29	0,874	4,06	0
20	5	0,114	0,127	1,90	33,54	5,66	5,31	0,898	4,18	1
20	6	0,104	0,132	1,82	25,53	7,13	7,62	0,788	5,27	2
20	7	0,104	0,134	1,90	22,18	8,57	9,29	0,776	6,33	2
21	1	0,084	0,124	1,84	44,03	4,18	5,19	0,677	3,09	0
21	2	0,105	0,124	1,83	35,69	5,13	5,10	0,847	3,79	0
21	3	0,112	0,124	1,78	32,28	5,51	5,14	0,903	4,07	0
21	4	0,115	0,124	1,86	32,37	5,75	5,22	0,927	4,24	1
21	5	0,118	0,127	1,90	31,90	5,96	5,40	0,929	4,40	2
21	6	0,105	0,129	1,94	23,75	8,17	8,45	0,814	6,03	2
21	7	0,106	0,134	1,90	18,41	10,32	10,99	0,791	7,62	2
22	1	0,068	0,124	1,82	47,67	3,82	5,86	0,548	2,82	0
22	2	0,085	0,124	1,76	37,14	4,74	5,82	0,685	3,50	0
22	3	0,103	0,124	1,84	32,21	5,71	5,79	0,831	4,22	0
22	4	0,110	0,124	1,80	29,54	6,09	5,78	0,887	4,50	0
22	5	0,113	0,124	1,80	28,73	6,27	5,79	0,911	4,63	0
22	6	0,116	0,125	1,86	28,88	6,44	5,84	0,928	4,76	0
22	7	0,119	0,126	1,77	26,57	6,66	5,94	0,944	4,92	1
22	8	0,109	0,132	1,78	21,44	8,30	8,47	0,826	6,13	2
22	9	0,109	0,135	1,88	20,00	9,40	9,80	0,807	6,94	2
23	1	0,075	0,125	1,76	42,45	4,15	5,82	0,600	3,06	0
23	2	0,092	0,125	1,84	35,86	5,13	5,87	0,736	3,79	0
23	3	0,104	0,125	1,79	31,02	5,77	5,84	0,832	4,26	0

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Table B.3 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
23	4	0,111	0,125	1,85	30,18	6,13	5,81	0,888	4,53	0
23	5	0,115	0,125	1,84	29,15	6,31	5,78	0,920	4,66	0
23	6	0,117	0,125	1,81	27,69	6,54	5,88	0,936	4,83	1
23	7	0,107	0,130	1,82	21,59	8,43	8,62	0,823	6,23	2
23	8	0,108	0,131	1,86	20,80	8,94	9,13	0,824	6,60	2
23	9	0,107	0,132	1,72	17,44	9,86	10,24	0,811	7,28	2
24	1	0,073	0,122	1,80	40,77	4,42	6,21	0,598	3,26	0
24	2	0,090	0,122	1,86	35,26	5,28	6,02	0,738	3,90	0
24	3	0,104	0,122	1,76	29,07	6,05	5,98	0,852	4,47	0
24	4	0,106	0,122	1,78	28,66	6,21	6,02	0,869	4,59	0
24	5	0,109	0,122	1,75	27,30	6,41	6,04	0,893	4,73	1
24	6	0,107	0,125	1,74	24,18	7,20	7,08	0,856	5,32	2
24	7	0,103	0,128	1,80	21,86	8,23	8,62	0,805	6,08	2
25	1	0,075	0,135	1,84	50,13	3,67	5,56	0,556	2,71	0
25	2	0,092	0,135	1,84	41,46	4,44	5,48	0,681	3,28	0
25	3	0,110	0,135	1,84	34,71	5,30	5,48	0,815	3,92	0
25	4	0,117	0,135	1,88	33,09	5,68	5,52	0,867	4,20	0
25	5	0,120	0,135	1,84	31,59	5,82	5,52	0,889	4,30	0
25	6	0,123	0,135	1,88	31,46	5,98	5,52	0,911	4,41	0
25	7	0,127	0,136	1,82	29,15	6,24	5,63	0,934	4,61	0
25	8	0,130	0,137	1,84	28,57	6,44	5,71	0,949	4,76	1
25	9	0,117	0,143	1,90	22,25	8,54	8,79	0,818	6,31	2
25	10	0,115	0,145	1,96	19,81	9,89	10,50	0,793	7,31	2
26	1	0,077	0,140	1,91	50,34	3,79	5,81	0,550	2,80	0
26	2	0,095	0,140	1,86	40,27	4,62	5,73	0,679	3,41	0
26	3	0,112	0,140	1,88	35,00	5,37	5,65	0,800	3,97	0
26	4	0,118	0,140	1,92	33,46	5,74	5,73	0,843	4,24	0
26	5	0,125	0,140	1,95	32,34	6,03	5,69	0,893	4,45	0
26	6	0,128	0,140	1,93	30,86	6,25	5,76	0,914	4,62	0
26	7	0,131	0,140	1,94	25,09	7,73	6,96	0,936	5,71	1
26	8	0,118	0,144	1,92	22,84	8,41	8,64	0,819	6,21	2
26	9	0,121	0,147	1,86	20,29	9,17	9,38	0,823	6,77	2
27	1	0,078	0,128	1,94	47,59	4,08	5,63	0,609	3,01	0
27	2	0,096	0,128	1,90	38,55	4,93	5,53	0,750	3,64	0
27	3	0,110	0,131	1,93	32,30	5,98	5,99	0,840	4,41	0
27	4	0,115	0,133	1,90	29,94	6,35	6,18	0,865	4,69	1
27	5	0,107	0,136	1,90	23,25	8,17	8,75	0,787	6,04	2
27	6	0,105	0,137	1,84	20,47	8,99	9,88	0,766	6,64	2
28	1	0,070	0,126	1,88	48,25	3,90	5,91	0,556	2,88	0
28	2	0,088	0,126	1,77	36,64	4,83	5,82	0,698	3,57	0

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Table B.3 – *Continued from previous page*

test	***measure***	***dh***	***L***	***dV***	***dt***	***Q***	***K***	***J***	***Re***	***failure***
		[m]	*[m]*	*10^{-3} [m^3]*	*[s]*	*10^{-5} [m^3/s]*	*10^{-3} [m/s]*	*[-]*	*[-]*	
28	3	0,101	0,126	1,86	33,68	5,52	5,80	0,802	4,08	0
28	4	0,108	0,126	1,86	31,90	5,83	5,73	0,857	4,31	0
28	5	0,111	0,126	1,86	31,03	5,99	5,73	0,881	4,43	0
28	6	0,114	0,126	1,84	29,52	6,23	5,80	0,905	4,60	0
28	7	0,118	0,126	1,93	30,24	6,38	5,74	0,937	4,71	0
28	8	0,120	0,126	1,90	28,61	6,64	5,87	0,952	4,91	1
28	9	0,110	0,132	1,86	21,50	8,65	8,74	0,833	6,39	2
28	10	0,110	0,134	1,88	19,88	9,46	9,70	0,821	6,98	2
29	1	0,069	0,124	1,82	47,69	3,82	5,77	0,556	2,82	0
29	2	0,087	0,124	1,92	40,76	4,71	5,65	0,702	3,48	0
29	3	0,099	0,124	1,94	35,51	5,46	5,76	0,798	4,04	0
29	4	0,104	0,126	1,93	32,30	5,98	6,10	0,825	4,41	0
29	5	0,108	0,128	1,92	30,25	6,35	6,33	0,844	4,69	1
29	6	0,104	0,131	1,83	22,23	8,23	8,73	0,794	6,08	2
29	7	0,102	0,132	1,90	20,90	9,09	9,91	0,773	6,71	2
30	1	0,063	0,126	1,86	54,13	3,44	5,79	0,500	2,54	0
30	2	0,080	0,126	1,93	44,31	4,36	5,78	0,635	3,22	0
30	3	0,096	0,126	1,90	36,69	5,18	5,72	0,762	3,82	0
30	4	0,108	0,126	1,95	33,32	5,85	5,75	0,857	4,32	0
30	5	0,117	0,126	1,90	29,88	6,36	5,77	0,929	4,70	1
30	6	0,109	0,131	1,94	25,01	7,76	7,85	0,832	5,73	2
30	7	0,108	0,133	1,98	22,52	8,79	9,12	0,812	6,49	2

B.4 Sample D measurements

All measurements were performed with a cylinder with a flow area of 0.01188 m^2 and water with a temperature of 16 ℃.

Table B.4: Measurements of sample D

test	*measure*	*dh* [m]	*L* [m]	*dV* 10^{-3} [m^3]	*dt* [s]	*Q* 10^{-5} [m^3/s]	*K* 10^{-3} [m/s]	*J* [-]	*Re* [-]	*failure*
1	1	0,068	0,119	1,86	39,05	4,76	7,02	0,571	3,52	0
1	2	0,081	0,119	1,90	34,57	5,50	6,80	0,681	4,06	0
1	3	0,089	0,119	1,89	30,59	6,18	6,96	0,748	4,56	0
1	4	0,096	0,119	1,92	28,77	6,67	6,97	0,807	4,93	0
1	5	0,100	0,119	1,85	26,70	6,93	6,94	0,840	5,12	0
1	6	0,102	0,119	1,92	26,94	7,13	7,00	0,857	5,26	0
1	7	0,104	0,119	1,91	26,29	7,27	7,00	0,874	5,37	0
1	8	0,105	0,119	1,94	26,15	7,42	7,08	0,882	5,48	0
1	9	0,107	0,119	1,92	25,44	7,55	7,07	0,899	5,57	1
1	10	0,096	0,124	1,92	22,53	8,52	9,27	0,774	6,29	2
1	11	0,097	0,125	1,82	20,19	9,01	9,78	0,776	6,66	2
2	1	0,066	0,119	1,82	43,66	4,17	6,33	0,555	3,08	0
2	2	0,083	0,119	1,90	37,12	5,12	6,18	0,697	3,78	0
2	3	0,094	0,119	1,88	32,30	5,82	6,20	0,790	4,30	0
2	4	0,107	0,119	1,94	29,04	6,68	6,26	0,899	4,93	0
2	5	0,109	0,119	1,94	28,49	6,81	6,26	0,916	5,03	0
2	6	0,111	0,119	1,92	27,37	7,01	6,33	0,933	5,18	0
2	7	0,114	0,120	1,94	26,63	7,29	6,46	0,950	5,38	0
2	8	0,117	0,120	1,93	25,80	7,48	6,46	0,975	5,53	1
2	9	0,106	0,124	1,92	21,02	9,13	9,00	0,855	6,75	2
2	10	0,105	0,126	1,89	18,91	9,99	10,10	0,833	7,38	2
2	11	0,105	0,127	1,91	16,71	11,43	11,64	0,827	8,44	2
3	1	0,076	0,134	1,89	33,98	5,56	8,26	0,567	4,11	0
3	2	0,090	0,134	1,81	27,56	6,57	8,23	0,672	4,85	0
3	3	0,103	0,134	1,82	24,49	7,43	8,14	0,769	5,49	0
3	4	0,108	0,134	1,85	23,58	7,85	8,20	0,806	5,79	0
3	5	0,114	0,134	1,76	21,30	8,26	8,18	0,851	6,10	1
3	6	0,107	0,136	1,88	21,17	8,88	9,50	0,787	6,56	2
3	7	0,106	0,137	1,80	19,33	9,31	10,13	0,774	6,88	2
4	1	0,076	0,127	1,80	33,69	5,34	7,52	0,598	3,95	0
4	2	0,090	0,127	1,82	28,95	6,29	7,47	0,709	4,64	0
4	3	0,103	0,127	1,84	25,90	7,10	7,38	0,811	5,25	0
4	4	0,108	0,127	1,83	24,52	7,46	7,39	0,850	5,51	0
4	5	0,113	0,127	1,90	23,90	7,95	7,52	0,890	5,87	0
4	6	0,116	0,127	1,90	23,38	8,13	7,49	0,913	6,00	0

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Table B.4 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
4	7	0,118	0,127	1,90	22,94	8,28	7,51	0,929	6,12	1
4	8	0,109	0,132	1,87	19,61	9,54	9,72	0,826	7,04	2
4	9	0,109	0,134	1,88	17,44	10,78	11,16	0,813	7,96	2
5	1	0,076	0,134	1,82	36,34	5,01	7,44	0,567	3,70	0
5	2	0,093	0,134	1,78	29,77	5,98	7,25	0,694	4,42	0
5	3	0,108	0,134	1,91	27,97	6,83	7,13	0,806	5,04	0
5	4	0,114	0,134	1,84	25,48	7,22	7,15	0,851	5,33	0
5	5	0,119	0,134	1,85	24,35	7,60	7,20	0,888	5,61	0
5	6	0,121	0,134	1,87	24,10	7,76	7,24	0,903	5,73	1
5	7	0,113	0,140	1,88	20,77	9,05	9,44	0,807	6,69	2
5	8	0,114	0,143	1,92	17,58	10,92	11,54	0,797	8,07	2
6	1	0,080	0,117	1,73	33,79	5,12	6,30	0,684	3,78	0
6	2	0,097	0,117	1,78	28,68	6,21	6,30	0,829	4,58	0
6	3	0,103	0,117	1,70	25,75	6,60	6,31	0,880	4,88	0
6	4	0,109	0,117	1,78	25,04	7,11	6,42	0,932	5,25	1
6	5	0,103	0,121	1,78	21,30	8,36	8,27	0,851	6,17	2
6	6	0,104	0,129	1,83	16,03	11,42	11,92	0,806	8,43	2
7	1	0,095	0,123	1,84	31,45	5,85	6,38	0,772	4,32	0
7	2	0,110	0,123	1,92	27,78	6,91	6,51	0,894	5,10	0
7	3	0,112	0,123	1,81	25,61	7,07	6,54	0,911	5,22	0
7	4	0,115	0,123	1,90	26,02	7,30	6,58	0,935	5,39	1
7	5	0,107	0,130	1,81	21,17	8,55	8,75	0,823	6,31	2
7	6	0,108	0,133	1,93	16,97	11,37	11,79	0,812	8,40	2
8	1	0,086	0,127	1,90	30,25	6,28	7,81	0,677	4,64	0
8	2	0,101	0,127	1,88	25,59	7,35	7,78	0,795	5,43	0
8	3	0,106	0,127	1,90	24,28	7,83	7,89	0,835	5,78	0
8	4	0,111	0,127	1,88	22,66	8,30	7,99	0,874	6,13	0
8	5	0,115	0,127	1,86	21,72	8,56	7,96	0,906	6,33	1
8	6	0,104	0,131	1,87	18,50	10,11	10,72	0,794	7,47	2
8	7	0,102	0,132	1,92	16,71	11,49	12,52	0,773	8,49	2
8	8	0,103	0,133	1,81	14,09	12,85	13,97	0,774	9,49	2
9	1	0,077	0,128	1,90	35,88	5,30	7,41	0,602	3,91	0
9	2	0,092	0,128	1,82	29,32	6,21	7,27	0,719	4,58	0
9	3	0,106	0,128	1,93	26,56	7,27	7,39	0,828	5,37	0
9	4	0,111	0,128	1,91	24,88	7,68	7,45	0,867	5,67	0
9	5	0,115	0,128	1,94	24,59	7,89	7,39	0,898	5,83	0
9	6	0,117	0,129	1,85	22,82	8,11	7,53	0,907	5,99	0
9	7	0,120	0,129	1,92	23,00	8,35	7,56	0,930	6,17	1
9	8	0,111	0,134	1,86	19,47	9,55	9,71	0,828	7,06	2
9	9	0,112	0,136	1,90	15,09	12,59	12,87	0,824	9,30	2

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Table B.4 – *Continued from previous page*

test	***measure***	***dh*** *[m]*	***L*** *[m]*	***dV*** *10^{-3} $[m^3]$*	***dt*** *[s]*	***Q*** *10^{-5} $[m^3/s]$*	***K*** *10^{-3} [m/s]*	***J*** *[-]*	***Re*** *[-]*	***failure***
10	1	0,080	0,115	1,79	33,82	5,29	6,41	0,696	3,91	0
10	2	0,096	0,115	1,91	30,19	6,33	6,38	0,835	4,67	0
10	3	0,102	0,115	1,86	27,47	6,77	6,43	0,887	5,00	0
10	4	0,107	0,115	1,82	25,44	7,15	6,47	0,930	5,28	1
10	5	0,101	0,121	1,84	21,56	8,53	8,61	0,835	6,30	2
10	6	0,101	0,126	1,83	15,12	12,10	12,71	0,802	8,94	2
11	1	0,084	0,123	1,86	33,07	5,62	6,93	0,683	4,15	0
11	2	0,101	0,123	1,85	27,78	6,66	6,83	0,821	4,92	0
11	3	0,114	0,125	1,92	24,44	7,86	7,25	0,912	5,80	0
11	4	0,116	0,126	1,96	24,35	8,05	7,36	0,921	5,95	1
11	5	0,106	0,130	1,94	20,29	9,56	9,87	0,815	7,06	2
11	6	0,106	0,133	1,96	16,53	11,86	12,53	0,797	8,76	2
12	1	0,092	0,121	1,82	28,71	6,34	7,02	0,760	4,68	0
12	2	0,105	0,121	1,89	25,53	7,40	7,18	0,868	5,47	0
12	3	0,109	0,121	1,88	23,72	7,93	7,41	0,901	5,85	1
12	4	0,104	0,126	1,90	20,59	9,23	9,41	0,825	6,82	2
12	5	0,100	0,128	1,98	16,71	11,85	12,77	0,781	8,75	2
13	1	0,094	0,130	1,87	29,75	6,29	7,32	0,723	4,64	0
13	2	0,106	0,130	1,88	26,25	7,16	7,40	0,815	5,29	0
13	3	0,111	0,130	1,92	25,57	7,51	7,40	0,854	5,55	0
13	4	0,114	0,130	1,82	23,16	7,86	7,55	0,877	5,80	0
13	5	0,116	0,130	1,90	23,88	7,96	7,51	0,892	5,88	0
13	6	0,118	0,131	1,90	23,10	8,23	7,69	0,901	6,08	1
13	7	0,104	0,135	1,91	20,62	9,26	10,12	0,770	6,84	2
13	8	0,106	0,137	1,86	18,41	10,10	10,99	0,774	7,46	2
13	9	0,107	0,138	1,82	15,85	11,48	12,47	0,775	8,48	2
14	1	0,078	0,117	1,90	35,60	5,34	6,74	0,667	3,94	0
14	2	0,094	0,117	1,90	29,66	6,41	6,71	0,803	4,73	0
14	3	0,100	0,117	1,90	27,75	6,85	6,75	0,855	5,06	0
14	4	0,106	0,118	1,88	26,24	7,16	6,72	0,898	5,29	0
14	5	0,108	0,119	1,94	25,75	7,53	6,99	0,908	5,56	1
14	6	0,102	0,123	1,90	21,29	8,92	9,06	0,829	6,59	2
14	7	0,104	0,126	1,90	17,22	11,03	11,26	0,825	8,15	2
15	1	0,087	0,135	1,88	33,13	5,67	7,41	0,644	4,19	0
15	2	0,103	0,135	1,88	27,96	6,72	7,42	0,763	4,97	0
15	3	0,115	0,135	1,86	23,81	7,81	7,72	0,852	5,77	0
15	4	0,122	0,136	1,84	22,19	8,29	7,78	0,897	6,12	0
15	5	0,124	0,136	1,86	21,75	8,55	7,90	0,912	6,32	1
15	6	0,116	0,139	1,86	19,47	9,55	9,64	0,835	7,06	2
15	7	0,115	0,142	1,96	17,22	11,38	11,83	0,810	8,41	2

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Table B.4 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
16	1	0,086	0,133	1,88	36,78	5,11	6,66	0,647	3,78	0
16	2	0,101	0,133	1,94	32,50	5,97	6,62	0,759	4,41	0
16	3	0,117	0,134	1,92	27,25	7,05	6,79	0,873	5,20	0
16	4	0,120	0,135	1,92	26,44	7,26	6,88	0,889	5,36	0
16	5	0,123	0,135	1,92	25,78	7,45	6,88	0,911	5,50	0
16	6	0,126	0,135	1,92	25,03	7,67	6,92	0,933	5,67	1
16	7	0,114	0,141	1,91	20,69	9,23	9,61	0,809	6,82	2
16	8	0,115	0,143	1,90	17,44	10,89	11,41	0,804	8,05	2
17	1	0,083	0,129	1,82	34,31	5,30	6,94	0,643	3,92	0
17	2	0,099	0,129	1,91	29,22	6,54	7,17	0,767	4,83	0
17	3	0,110	0,131	1,93	26,21	7,36	7,38	0,840	5,44	0
17	4	0,115	0,131	1,96	25,04	7,83	7,51	0,878	5,78	0
17	5	0,117	0,132	1,91	23,69	8,06	7,66	0,886	5,96	1
17	6	0,108	0,136	1,94	21,15	9,17	9,73	0,794	6,77	2
17	7	0,111	0,139	1,98	18,09	10,95	11,54	0,799	8,08	2
18	1	0,074	0,129	1,85	38,35	4,82	7,08	0,574	3,56	0
18	2	0,088	0,129	1,94	34,12	5,69	7,02	0,682	4,20	0
18	3	0,100	0,129	1,92	29,53	6,50	7,06	0,775	4,80	0
18	4	0,111	0,130	1,98	27,60	7,17	7,07	0,854	5,30	0
18	5	0,115	0,130	1,85	24,53	7,54	7,18	0,885	5,57	0
18	6	0,117	0,130	1,93	25,06	7,70	7,21	0,900	5,69	0
18	7	0,119	0,131	1,92	24,35	7,89	7,31	0,908	5,82	1
18	8	0,106	0,134	1,93	21,44	9,00	9,58	0,791	6,65	2
18	9	0,105	0,137	1,93	18,87	10,23	11,24	0,766	7,55	2
19	1	0,085	0,126	1,84	34,65	5,31	6,63	0,675	3,92	0
19	2	0,100	0,126	1,84	29,31	6,28	6,66	0,794	4,64	0
19	3	0,115	0,126	1,86	24,87	7,48	6,90	0,913	5,52	0
19	4	0,117	0,126	1,86	24,31	7,65	6,94	0,929	5,65	1
19	5	0,108	0,133	1,84	19,81	9,29	9,63	0,812	6,86	2
19	6	0,108	0,137	1,84	15,09	12,19	13,02	0,788	9,01	2
20	1	0,084	0,125	1,86	35,19	5,29	6,62	0,672	3,90	0
20	2	0,099	0,125	1,86	29,93	6,21	6,61	0,792	4,59	0
20	3	0,113	0,125	1,83	25,47	7,18	6,69	0,904	5,31	0
20	4	0,116	0,127	1,86	25,06	7,42	6,84	0,913	5,48	0
20	5	0,119	0,128	1,87	24,47	7,64	6,92	0,930	5,64	1
20	6	0,106	0,134	1,86	20,09	9,26	9,85	0,791	6,84	2
20	7	0,108	0,137	1,88	16,84	11,16	11,92	0,788	8,25	2
21	1	0,086	0,118	1,88	32,63	5,76	6,66	0,729	4,26	0
21	2	0,100	0,118	1,88	27,75	6,77	6,73	0,847	5,00	0
21	3	0,105	0,118	1,89	26,47	7,14	6,76	0,890	5,27	0

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Table B.4 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
21	4	0,108	0,118	1,89	25,75	7,34	6,75	0,915	5,42	0
21	5	0,111	0,118	1,86	24,78	7,51	6,72	0,941	5,54	1
21	6	0,100	0,123	1,88	20,75	9,06	9,38	0,813	6,69	2
21	7	0,102	0,128	1,80	17,16	10,49	11,08	0,797	7,75	2
22	1	0,077	0,130	1,87	31,82	5,88	8,35	0,592	4,34	0
22	2	0,094	0,130	1,90	27,37	6,94	8,08	0,723	5,13	0
22	3	0,108	0,130	1,86	23,25	8,00	8,11	0,831	5,91	0
22	4	0,114	0,131	1,88	22,13	8,50	8,22	0,870	6,27	0
22	5	0,116	0,131	1,94	22,16	8,75	8,32	0,885	6,47	1
22	6	0,109	0,133	1,92	19,22	9,99	10,26	0,820	7,38	2
22	7	0,109	0,137	1,94	16,28	11,92	12,61	0,796	8,80	2
23	1	0,071	0,132	1,90	37,13	5,12	8,01	0,538	3,78	0
23	2	0,085	0,132	1,92	31,50	6,10	7,97	0,644	4,50	0
23	3	0,099	0,132	1,86	26,15	7,11	7,99	0,750	5,25	0
23	4	0,110	0,133	1,90	24,13	7,87	8,02	0,827	5,82	0
23	5	0,116	0,133	1,92	23,15	8,29	8,01	0,872	6,13	0
23	6	0,118	0,133	1,96	23,19	8,45	8,02	0,887	6,24	1
23	7	0,112	0,136	1,87	19,53	9,58	9,79	0,824	7,07	2
23	8	0,113	0,139	1,94	17,00	11,41	11,82	0,813	8,43	2
24	1	0,082	0,128	1,86	31,53	5,90	7,75	0,641	4,36	0
24	2	0,097	0,128	1,87	27,00	6,93	7,70	0,758	5,12	0
24	3	0,108	0,128	1,88	24,25	7,75	7,74	0,844	5,73	0
24	4	0,113	0,129	1,88	22,75	8,26	7,94	0,876	6,10	0
24	5	0,115	0,129	1,91	22,56	8,47	8,00	0,891	6,25	0
24	6	0,117	0,129	1,86	21,59	8,62	8,00	0,907	6,36	1
24	7	0,108	0,133	1,93	19,53	9,88	10,25	0,812	7,30	2
24	8	0,109	0,136	1,91	16,38	11,66	12,25	0,801	8,61	2
25	1	0,079	0,134	1,08	23,47	4,60	6,57	0,590	3,40	0
25	2	0,101	0,134	1,36	23,32	5,83	6,51	0,754	4,31	0
25	3	0,117	0,134	1,53	22,41	6,83	6,58	0,873	5,04	0
25	4	0,123	0,134	1,54	21,19	7,27	6,67	0,918	5,37	0
25	5	0,126	0,134	1,72	23,12	7,44	6,66	0,940	5,49	1
25	6	0,114	0,141	1,67	17,63	9,47	9,87	0,809	7,00	2
25	7	0,116	0,145	1,78	15,38	11,57	12,18	0,800	8,55	2
26	1	0,089	0,140	1,21	22,94	5,27	6,99	0,636	3,90	0
26	2	0,105	0,140	1,40	22,72	6,16	6,92	0,750	4,55	0
26	3	0,120	0,140	1,56	21,82	7,15	7,02	0,857	5,28	0
26	4	0,126	0,140	1,67	22,31	7,49	7,00	0,900	5,53	0
26	5	0,128	0,140	1,60	20,63	7,76	7,14	0,914	5,73	1
26	6	0,118	0,144	1,74	18,75	9,28	9,54	0,819	6,85	2

Continued on next page

Table B.4 – *Continued from previous page*

test	***measure***	***dh*** [m]	***L*** [m]	***dV*** 10^{-3} [m^3]	***dt*** [s]	***Q*** 10^{-5} [m^3/s]	***K*** 10^{-3} [m/s]	***J*** [-]	***Re*** [-]	***failure***
26	7	0,119	0,149	1,84	16,40	11,22	11,83	0,799	8,29	2
27	1	0,096	0,131	1,33	23,21	5,73	6,58	0,733	4,23	0
27	2	0,109	0,131	1,53	23,58	6,49	6,57	0,832	4,79	0
27	3	0,121	0,131	1,66	22,43	7,40	6,75	0,924	5,47	0
27	4	0,123	0,131	1,66	22,06	7,52	6,75	0,939	5,56	1
27	5	0,110	0,135	1,54	17,87	8,62	8,91	0,815	6,37	2
27	6	0,112	0,140	1,87	17,47	10,70	11,27	0,800	7,91	2
28	1	0,079	0,132	1,81	32,41	5,58	7,86	0,598	4,12	0
28	2	0,094	0,132	1,78	26,56	6,70	7,92	0,712	4,95	0
28	3	0,109	0,132	1,92	24,97	7,69	7,84	0,826	5,68	0
28	4	0,115	0,133	1,88	23,32	8,06	7,85	0,865	5,95	0
28	5	0,117	0,133	1,85	22,19	8,34	7,98	0,880	6,16	0
28	6	0,120	0,134	1,78	20,88	8,52	8,02	0,896	6,30	1
28	7	0,112	0,137	1,86	18,85	9,87	10,16	0,818	7,29	2
28	8	0,114	0,141	1,88	15,60	12,05	12,55	0,809	8,90	2
29	1	0,070	0,125	1,88	37,44	5,02	7,55	0,560	3,71	0
29	2	0,085	0,125	1,78	29,63	6,01	7,44	0,680	4,44	0
29	3	0,099	0,125	1,88	27,06	6,95	7,39	0,792	5,13	0
29	4	0,104	0,125	1,84	25,00	7,36	7,45	0,832	5,44	0
29	5	0,110	0,125	1,88	24,06	7,81	7,48	0,880	5,77	0
29	6	0,112	0,126	1,82	22,75	8,00	7,58	0,889	5,91	0
29	7	0,115	0,126	1,80	21,87	8,23	7,59	0,913	6,08	1
29	8	0,106	0,128	1,82	18,87	9,64	9,81	0,828	7,12	2
29	9	0,110	0,132	1,86	15,87	11,72	11,84	0,833	8,66	2
30	1	0,072	0,129	1,73	32,88	5,26	7,94	0,558	3,89	0
30	2	0,085	0,129	1,90	31,03	6,12	7,82	0,659	4,52	0
30	3	0,097	0,129	1,83	26,22	6,98	7,82	0,752	5,16	0
30	4	0,108	0,129	1,78	22,84	7,79	7,84	0,837	5,76	0
30	5	0,113	0,130	1,86	22,88	8,13	7,87	0,869	6,00	0
30	6	0,115	0,130	1,86	22,35	8,32	7,92	0,885	6,15	1
30	7	0,108	0,131	1,90	20,78	9,14	9,34	0,824	6,75	2
30	8	0,108	0,135	1,83	17,50	10,46	11,01	0,800	7,72	2