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Rainfall Simulator RS-TUHH – Planning, Construction and Use

G. Palmaricciotti, J. Patzke, S. Hellmers, N. Manojlovic & P. Fröhle
Institute for river and costal engineering, TU Hamburg-Harburg, Germany

ABSTRACT: In this paper the development, construction and use of a rainfall simulator (RS-TUHH) are described. On a testing area of 1m² different drop forming measures have been analysed before the simulator was constructed. The RS-TUHH uses ending grid heads with a grid space of 6 cm and an underlying drop splitting net.
The simulator consists of four parts: the pipe pressure and water distribution module, the aluminum structure, the irrigation system and the drop splitting net.
As it is built, the shaped plot area of 6 m² can be divided in to 3 sectors á 2 m². The main intention is to imitate natural rainfall by reproducing parameters like rainfall velocity, intensity and duration, as well as drop size, amount and distribution. Experimental parameters are measured with laser precipitation monitor (by ThiesClima) and rain collectors. The RS-TUHH is able to imitate natural heavy rain events of different intensities from 3 to 200 mm/h on three sizes of plot areas with any duration. Intensity and duration are set by the control module. Drop size distribution and drop amount depend on the used net grid space. Spatial distribution is homogeneous over the plot area. Fall velocities are low compared to natural rain.

Keywords: Rainfall simulation, Intensity, Drop size, Drop velocity, Rainfall Runoff model

1 INTRODUCTION

During the last decades new concepts and approaches have been developed in flood protection and rainwater management in order to cope with climate change and urbanization. In particular, central systems for the collection and conveyance of rainwater have slowly lost ground in favor of more sustainable technics which promote on-site infiltration, evaporation and reuse.

In Germany, the heavy flood events in 2002 first and in 2013 after drove to a new call for change. The funding for reconstruction and for research i.e. planning and implementation of adaptation measures led to new construction schemes. A prestigious project was started in Berlin within the framework of the rearrangement of the old Tempelhofer airport into a sustainable water treatment plant, which represents a new target in the whole rainwater management plan. Another example is found in the district of Wilhelmsburg in Hamburg, where a concept for a sustainable rainwater management was developed and implemented for a 35 Km² area within the scope of the international building exhibition.

The growing involvement of the community in such projects increases the public awareness toward sustainable water management as well as the understanding of the adaptation measures.

To foresee and quantify the effects of the adaptation measures numerical and physical models are needed. In this work the development, construction and use of an experimental station to simulate rainwater close to reality are presented. Rainwater simulation represents a crucial point within the studies of soil erosion ((Iserloh, 2013), (Cerdà, 1999), (Schmidt, 09-2005), (R.Pall, 02.1983)). However, the original purpose for the construction of the RS-TUHH simulator was the analysis of the measures of the rainwater management. Therefore, in this study the focus lies on the control of the parameters such as intensity and distribution of the rain.

1.1 *Theoretical background*

With the aim of predicting rainfall events, in the period between 1961 and 1969 (Geissles, 2003) precipitations were continuously recorded and interpreted. Subsequently, on the basis of the collected information, regional design rainfall data with representative duration and returning period were developed. These represent the required assessment basis for the construction of facilities for the management of rainwater and wastewater according to the codes of practice.

According to these specifications, for the rainfall simulator presented in this work the target was set to $r_{100a/D15}$ i.e. to achieve an intensity equal to an event with 100 year returning period and 15 minutes duration. Relatively to the rainfall series of the city of Hamburg (Geissler, 2003) this means an intensity of 300 l/s/ha which corresponds to 27 mm.

Currently, rainwater simulators are manly used in the field of soil erosion (J. Fernandez-Galvez, 2008) (R.Pall, 02.1983) (Cerdà, 1999) (Iserloh, 2013)). In his research, Iserloh (Iserloh, et al., 2013) compared existing simulators examining their characteristics and assumptions. He concludes that no exact reproductions can be achieved under laboratory conditions due to the spatial and temporal inconstancy of natural precipitations. However, although this standardization of natural rainfall events in experimental simulations means a leveling of real highly variable processes, it makes it possible to collect relevant and comparable data. With respect to the experiments with rainfall simulators Iserloh highlights as critical amongst others parameters intensity, spatial distribution, drop distribution and fall velocity.

2 MATERIALS AND METHODS

2.1 *Development, description and use of rainfall simulator RS-TUHH*

The first task was finding out a system to form water droplets. The two possibilities were: single drop creation or spraying nozzles. In order to develop a method to reproduce precipitations in a more representative way, the single drop system was chosen.

2.1.1 *Test phase*

As orientation for the development of a single drop creation system, the characteristics of a rainwater simulator developed in Kiel were analyzed. At first a structure was built out of aluminum profiles with a base of 1x1 m² and 2.5 m high (s. Figure 1).

Figure 1. Test simulator of 1 m²

Figure 2. Water tank and net

This was helpful for the selection of methods and materials for the construction of the final simulator.

Following the Kiel experience, the first system was created, which consisted of a 1 m² tank with holes of 1 mm diameter distributed in a matrix of 6 cm. The water tank was then fixed on top of the aluminum structure. Below the tank, a net was stretched, which was used to split the drops into smaller ones

(s. Figure 2). For the first experiments, a net with a 3 mm mesh was placed 50 cm below the tank. Drop amount and fall velocity measured using these settings resulted to be quite similar to those measured at the Kiel simulator. However, the system showed several limitations. First of all, the intensity of the rain could be set only by controlling the water level in the tank. Additionally, noticeable differences in amount of water passing through were observed between the center and the area next to the walls of the tank. This was mainly caused by inflection of the bottom side under the weight of the water. Finally, the tank was already in its small test version quite heavy and unhandy to move. These considerations led to the discard of this method.

2.1.2 *Drop forming plates*

In the light of the gained experience a new method was analyzed. The system consisted in a matrix of endline drip heads 2 litres per hour, which are used for irrigation in agriculture. The droplets generated using this method have a size between 3 and 6 mm. In order to reach the desired threshold of 300 l/(s*ha) as well as a homogeneous distribution of the rainwater through the testing area, a system of 50 tubes and 1650 endline drip heads was built (s. Figure 3). Thanks to the integration of a water distribution system, the irrigated area can be divided into 3 sectors á 2 m². Each 2 m² area is irrigated from an independent system which is equipped with 2 inlets to guarantee an equal distribution of pressure within the tubes and 2 outlets to allow a quick drainage of the tubes.

Figure 3. Single drop creation method “endline drip heads”

2.1.3 *Drop distribution mesh*

Since the endline drip heads can only generate drops of the same size under constant pressure, below the tube system a net is allocated. Besides the creation of a new spectrum of drop size, the impact against the net provides a homogeneous distribution through the whole testing area (s. Figure 4).

Figure 4. example of drop splitting and distributing net, with 3mm grid

2.1.4 *Control of experiment parameters*

A water distribution mechanism was built to regulate the intensity and to select the irrigated area (2, 4 or 6 m²). The input flow is controlled by a pressure relief valve and is recorded by a flow-meter. Thanks to a system of pipe junctions, the flow can be split into six outlets, i.e. two inflow for each irrigation plate. The values of inflow and rainfall intensity are continuously recorded and compared.

2.2 *Measuring equipment*

2.2.1 *Thies precipitation monitor*

For the analysis of the simulated precipitation a Laser-Precipitation-Monitor (LNM), manufactured from the company Thies, is used. According to Iserloh the LNM is currently the most precise and widely spread method for measuring precipitation characteristics. The LNM is able to record and classify the drops according to size, number and fall velocity.

2.2.2 *TUHH Pluviometer*
Besides the LNM, rain gauges developed at the TUHH (according to DIN 58666) are used (s. Figure 5). These stations record the weight of the rainwater falling within the measuring surface (200 cm²). By using several stations, the distribution of the rainfall over the testing area can be analyzed as well as the intensity over the time.

Figure 5. Rain gauges developed at the TUHH

2.2.3 *Rainfall collectors*
Another simple method was adopted to analyze the homogeneity of the simulated rainfall i.e. by using rainwater collectors. This was done for the whole testing area (6 m²) as well as for the single plates (2 m²).

2.2.4 *Parameters of rainfall simulator*
In summary the rainfall simulator consists of the dimensions given in Table 1. Figure 6 gives a prediction of how the simulator looks in experiments.


Figure 6. Rainfall demonstration without net, RS-TUHH

Table 1. Dimensions of RS-TUHH

Parts and size of the RS-TUHH	
Simulator dimensions	**Size**
Height [m]	2.8
Long [m]	3.16
Large [m]	2.5
Testing area [m²]	1x2 / 2x2 / 3x2
Form	rectangular
Max fall height [m]	2.75
Net height [m]	variable
Intensity [mm/h]	3-200
Duration	variable
Precipitation type	Heavy rain, drizzling rain, uniform drops
Distribution module	**Size**
Pressure regulator [bar]	0 - 6
Flow meter [l/min]	0,5-16
Flow meter [bar]	0-10
Junctions [-]	6

3 RESULTS

3.1.1 *Spatial rainfall distribution*

Figure 7 shows exemplary the results of the spatial distribution of the rainfall for one of the irrigation plate (test area 2 m²). By dividing the area in 4 sectors the maximum deviation from the mean was smaller than 3%.

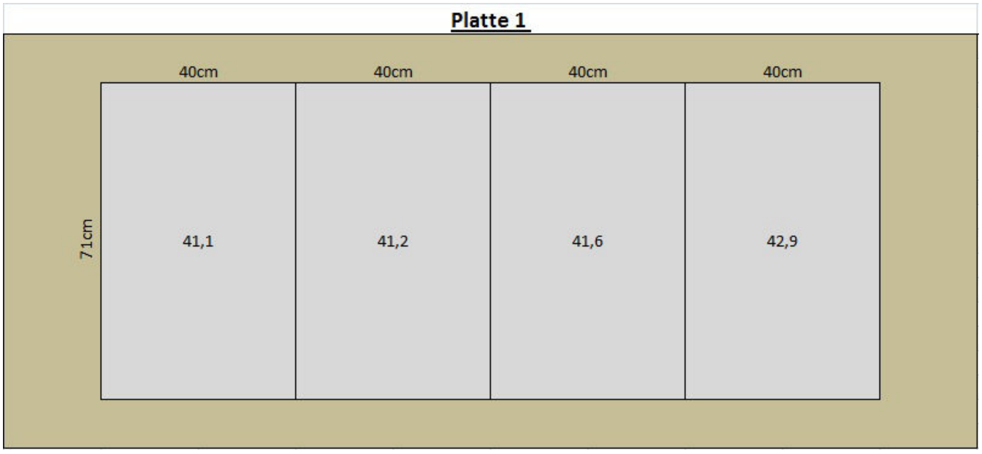

Figure 7. Spatial rainfall distribution on plate 1, measured with rainfall collectors

3.1.2 *Precipitation characteristics*

In order to present the values of fall velocity and drop size recorded by the LNM device, a spread sheet was developed, which tabulates the most important data of the test.

In Figure 8 a graphic representation of the results is shown for different intensities, with and without splitting net and for natural rainfall.

Figure 8. Example of output of rainfall character: drop size vs fall velocities

3.2 *Intensity*

Several tests have been conducted to proof the constancy of the intensity. Within a 30 minutes test by a medium intensity of 20 mm/h the oscillation recorded was maximum 5 mm/h (s. Figure 9). These values were recorded with the LNM device and evaluated with the software LNM-View and with an excel sheet. Generally, for higher intensities a bigger range of variation should be expected. However, other factors depending on the measuring instrument, the data conversion software and the water pressure (from the tap) might influence these variations too. Therefore an intensity variation recorded by the LNM does not necessarily means an overall difference through the whole test area. Intensities between 3 and 200 mm/h were measured, which could be kept constant for over 30 minutes. The upper limit can be more than doubled by using a pump instead of direct connection to tap water.

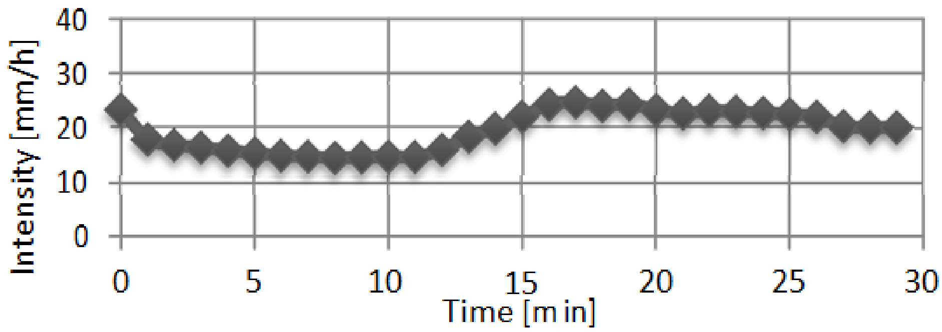

Figure 9. 30-minutes intensity measurment

3.3 *Drop size distribution*

The drop size distribution was analyzed by changing the net configuration for a given intensity as well as by modifying the intensity by a fixed net configuration. Figure 10 shows the results of several simulations carried out keeping the net configuration and increasing the intensity. It appears that the increasing intensity does not affect the drop size distribution.

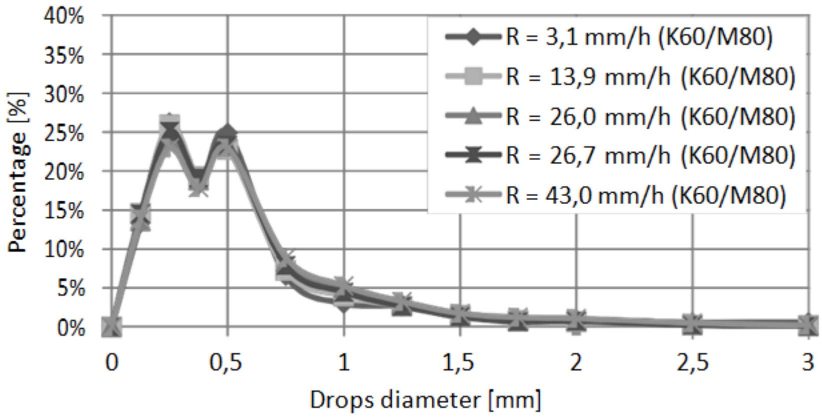

Figure 10. Drop size distribution for different intensities with net configuration (K60/M80)

To be able to simulate the drop size distribution of a specific natural rainfall an adequate configuration of the net is required. Figure 11 shows the comparison between a simulated and a natural rainfall of similar intensity. In both it appears that most of the drops have a size within 0.25 and 0.75 mm and 4 mm it's the top limit.

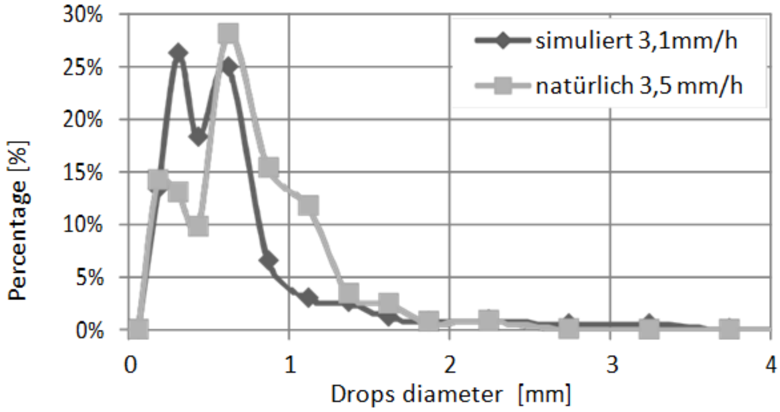

Figure 11. Comparison of drop diameters for natural and simulated (K60/M80) rain at an intensity of 3 mm/h

3.4 *Fall velocities*

The fall velocities of the drops generated with the RS-TUHH are limited due to the maximum fall height of 2.75 m. The drops generated through the impact with the net reach a velocity of approximately 2 m/s while for natural rainfall, even for lower intensity, the average velocity varies between 2 and 4 m/s, Figure 12. By adjusting the configuration of the net, the fall velocity can be increased. However, even when removing the net the simulated drop does not reach the fall velocity of the natural one (s. Figure 13).

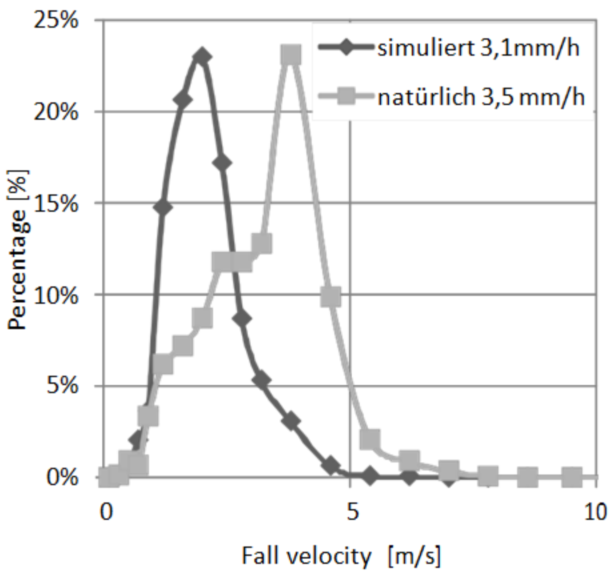

Figure 12. Comparison of fall velocities for natural and simulated rain at small intensities

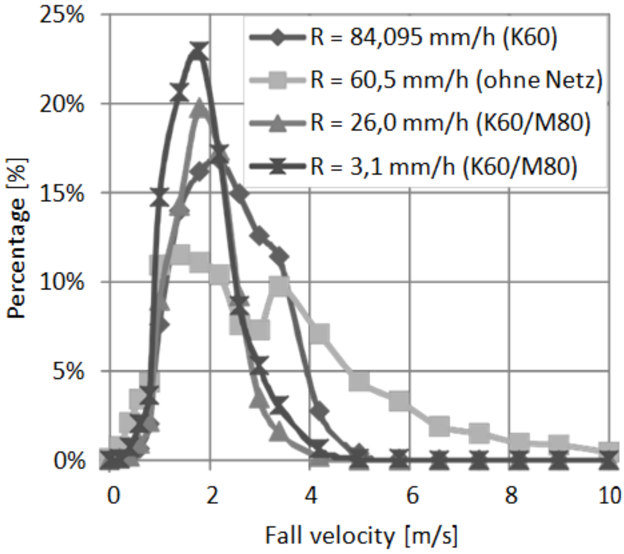

Figure 13. Comparison of fall velocities for different intensities

3.5 *Summary of the results*

This work presents the results of the first tests run with the rainfall simulator (RS-TUHH) for the definition of the main parameters (s. Table 2). Laboratory tests showed that the RS-TUHH can reproduce rainfall intensities between 3 and 200 mm/h. The drop size distribution might be adapted to better resemble that of natural rainfall by using a net. Due to the limited fall height, the average fall velocities of the simulated rainfalls result to be smaller than those of the natural ones.

Table 2. Parameter measured with the RS-TUHH

Parameter	**Value**
Drop size range [mm]	0.125 - 5
Average drop size [mm]	0.4 – 0.65
Fall velocity range [m/s]	0.2 - 6
Average fall velocity [m/s]	1.8 – 2.6
Intensity [mm/h]	3 - 200
Average spatial deviation	3%

4 CONCLUSIONS

The original intention of developing a rainwater simulator capable of irrigating a testing area of 6 m² with different precipitation intensities was successfully achieved.

To form the drops ending drip heads were used, an established technique in the field of gardening and agriculture. To reproduce a realistic spectrum of drop size a net was fixed below the irrigation system. Several methods were used to measure the spatial distribution and the intensity of the simulated rainfall over the testing area. Where possible, the characteristics of natural and simulated rainfall within the same order of intensity were compared.

The functionality to split the testing area into 3 sectors increases the efficiency of the simulator as well as the variety of possibilities. With its 6 m² testing area the RS-TUHH allows for tests at physical models with a 1:1 scale and in particular, for analysis of characteristics and limitations of products and materials which have to withstand heavy rainfall.

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