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UNCERTAINTY ASSESSMENT OF RAINFALL SIMULATOR UNIFORMITY COEFFICIENT

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Summary: *In the past sixty years several methods for the assessment of rainfall distribution over the surface has developed, but the method proposed by Christiansen is mostly used. Depending on the type of simulator, type of the nozzle and the size of a surface, Christiansen's coefficient varie from 0.6 to 0.95. This paper presents a method for determining Christiansen's coefficient of uniformity and assessment of its ambiguity due to measurement uncertainty of associated equipment. Rainfall intensities of up to 3.1 mm/min with a uniformity coefficient up to 0.85 can be achieved with this simulator.*

Keywords: *Uniformity coefficient, rainfall simulator, uncertainty*

1. INTRODUCTION

Rainfall simulators are used in laboratory studies, in controlled conditions, of drainage process, erosion or infiltration. Even though they have an advantage of controlling the rainfall intensity, rainfall depth and duration, it is not an easy task to reproduce all characteristics of natural rainfall.

Rainfall distribution over the surface is one of the basic requirements that rainfall simulator must satisfy. It depends on the distance between the nozzles, operating pressure, nozzle diameter and variable natural features such as direction and wind speed [1].

Several methods for the assessment of rainfall distribution over the surface has been developed, but the method proposed by Christiansen is mostly used [2]. To analyze the influence of nozzle spacing in irrigation systems on water distribution over the surface, Christiansen introduced the uniformity coefficient u defined as [3]:

$$u = 1 - \left(\sum \left| x_i - x_{avg} \right| / \sum x_i\right) \tag{1}$$

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where x_i is volume of water in an individual container, and x_{avg} is average volume of water from all containers. For the ideal spatial rainfall distribution, value of Christiansen's coefficient is 1. In order to simulate small intensity rainfalls, Williams [4] constructed a rainfall simulator that uses HH-SS14SQW nozzles and covers an area of 1.5x9.1 m. Nozzles were placed above the rotating disc with a hole and simulator achieves rainfall intensities between 4.5-35.8 mm/h under a nozzle pressure of 100 kPa. Depending on the rainfall intensity and openness of the disc, Christiansen's uniformity coefficient had a value of 0.76-0.80. Walnut Gulch [5] rainfall simulator is equipped with a step-motor which rotates the pipe with the nozzles at a speed dependent on the position of the nozzle. Simulator uses four VeeJet 80100 nozzles and is able to reproduce rainfall intensities of 13-200 mm/h. Nozzles are placed above the box with an opening, at a height of 2.44 m, covering the surface of 2x6.1 m. To determine uniformity coefficient, 28 containers (34x5.8x6.4 cm) are evenly distributed over the surface. For rainfall intensities between 13-130 mm/h uniformity coefficient is 0.927, and with intensities between 140-200 mm/h value of the coefficient is 0.916.
A portable rainfall simulator, constructed by Sobrinho [6], which is intended to simulate process of runoff from the surface of 0.78 m^2, can simulate rainfall intensities of 30-155 mm/hr. Simulator uses two types of nozzles, VeeJet 80100 and 80150, which are placed above the rotating disk with a hole, with the spacing of 0.4 meters between nozzles and at a height of 2.3 meters from the ground surface. For the first type of the nozzle working pressure was 32.7 kPa, while operating pressure for the second type of the nozzle was 36.5 kPa. To determine coefficient of uniformity, author used 42 cups (120x80 mm) in which he collected water during 12 minutes rainfall duration, varying intensities of the rainfall. Each experiment was repeated three times. The results show that uniformity coefficient is within the range of 0.81-0.85, and the uncertainty in the range is 0.010-0.029. To determine erosion due to simulated rainfall under the influence of the wind, Fister [7] constructed a rainfall simulator which covers an area of 4x0.7 m and reproduce rainfall intensities of 85-95 mm/h. Simulator uses four Lechler 460.608 nozzles mounted at a height of 0.7 meters and at apart distance of 0.75 m. Working pressure was 20 kPa. With five replications of five minute rainfalls, using laser precipitation monitor, rated Christiansen's uniformity coefficient for this simulator was 0.6. Although the uniformity of rainfall is prerequisite for successful exploitation and analysis of rainfall simulator results, available literature does not provide much about methods used to calculate the uniformity coefficient neither the assessment of its uncertainty. The aim of this paper is to present a method for calculating Christiansen's uniformity coefficient and evaluation of its uncertainty. Method is shown on the example of rainfall simulator developed at the Faculty of Civil Engineering in Subotica

2. METHODS

2.1. Rainfall simulator

The simulator uses six VeeJet 80100 nozzles placed on a horizontal pipe with the 50 mm diameter and the 6 m length. Due to the slow water velocities, the specified pipe diameter allows constant water pressure of 40 kPa in all nozzles. Water supply connection is located at the middle of the pipe, between nozzles 3 and 4 (Fig. 1). The nozzles are located at equal spacing of 100 cm and 4.5 m above the surface in its horizontal position. Maximum surface covered by the simulator is 6 m^2.

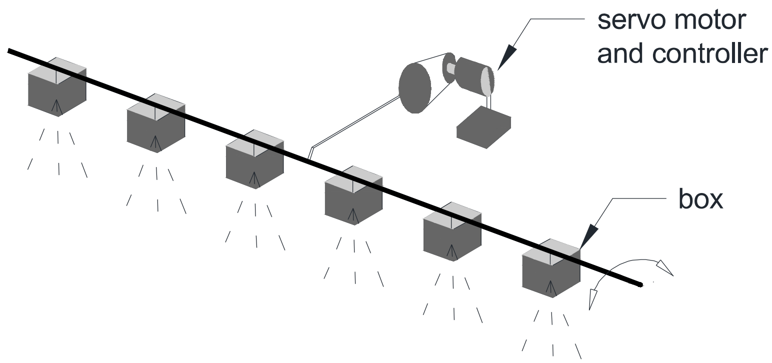

Figure 1. Rainfall simulator

A box for rainfall intensity reduction is placed under each nozzle (Fig. 2). The box dimensions are 0.4 x 0.4 x 0.2 m. Its upper side is fully open, while the lower side has three holes. Water coming out from the nozzles falls down through the central square hole 0.16 x 0.16 m. The other two smaller circular holes are used to drain excess water from the box back into the tank.

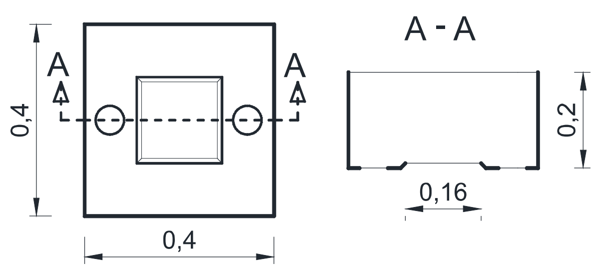

Figure 2. The box for reducing the rainfall intensity

Capacity of the water supply tank is 500 liters. Using the centrifugal pump, water is conveyed from the tank to the pipe with nozzles. The system pressure is controlled by the valves placed downstream from the pump.

2.2. Measuring procedure

The system for controlling the rainfall simulator includes servo motor, controller and two sprocket wheels with the chain. This system enables oscillatory movement of nozzles for ± 45° (Fig. 3), thus enabling adjustment of rainfall intensity by changing time during which the nozzle is not covering central hole.
Before the beginning of each experiment, until the system pressure is stabilized, the nozzles are placed in the farthest position in which water cannot fall on the surface (Fig.

3a). With nozzles in this position water spray does not go through the central hole, but goes through the gutter that conveys water back to the tank. When the system pressure is stabilized at 40 kPa, the engine that rotates the pipe is started by the controller. Rotation of the pipe moves the nozzle, which travels above the central hole (Fig. 3b) and stops at the other end position. The time nozzle spends in the farthest positions determines the intensity of rain falling on the experimental surface.

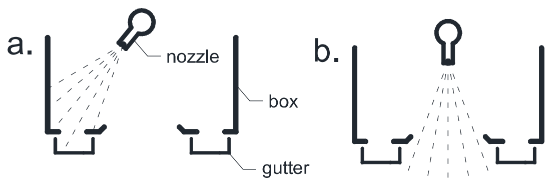

Figure 3. a. the farthest position of a nozzle, b. working position of a nozzle

By oscillating the nozzle above the box, this simulator can produce maximum rainfall intensity of 186 mm/h (3.1 mm/min), which generally covers the highest rainfall intensities occurring locally (according to Zelenhasic [8], intensities of 10-minute storms of 100 years return period in Serbia range up to 3.5 mm/min).
To determine Christiansen's uniformity coefficient, area size of 6x1 m is divided into six parts – sized 1x1 m, on which are evenly distributed 288 containers with a diameter of 5 cm (48 containers per m^2) (Fig. 4). After stabilizing the pressure, at a rainfall intensity of 3.1 mm/min, the water has been accumulated in containers for 5 minutes. The water distribution over the surface, separately for each area size of 1x1 and a total surface size of 6x1 m, was determined by measuring the mass of water in each container on a scale of 1 g precision. On the basis of the equation (1) the uniformity coefficient is calculated.

2.3. Assessment of uncertainty

For each surface size of 1x1 m, using measured weight of the water in the containers and the equation (1), uniformity coefficient is determined in accordance with the type A evaluation method [9]. Measurement uncertainty expressed as coefficient *u*, is presented as standard deviation from the mean, and is calculated on basis of the expression:

$$u_u = \sqrt{\frac{\sum_{i=1}^{6}\left(u_i - u_s\right)^2}{n\left(n-1\right)}} \tag{2}$$

where u_i is the uniformity coefficient for area size of 1x1 m, u_s average value of uniformity coefficients from the areas of 1x1 m and n is the number of data.
Given that standard deviation is determined with only six calculated coefficients of uniformity and assuming that the mean follows the Student distribution, expanded uncertainty U is also determined:

$$U = k \cdot u_u \tag{3}$$

where k is a coverage factor and for a particular case, for the confidence interval of 95%, it has a value of 2.78.

3. RESULTS

By measuring the weight of water collected in the 5 cm diameter containers, Christiansen's uniformity coefficients are determined for six areas of 1x1 m in size:

Table 1. Christiansen's uniformity coefficients for 1x1 m area sizes

Area	1	2	3	4	5	6
u	0.85	0.82	0.79	0.83	0.79	0.84

Average value of uniformity coefficient is 0.82. Using equation (2), estimated coefficient has uncertainty of 0.011 and the expanded measuring uncertainty, according to equation (3), is 0.031.
Distribution of water over the surface dimensions of 6x1 meters is shown in Figure 4, and is presented as percentage of the maximum amount of the collected water in a container.

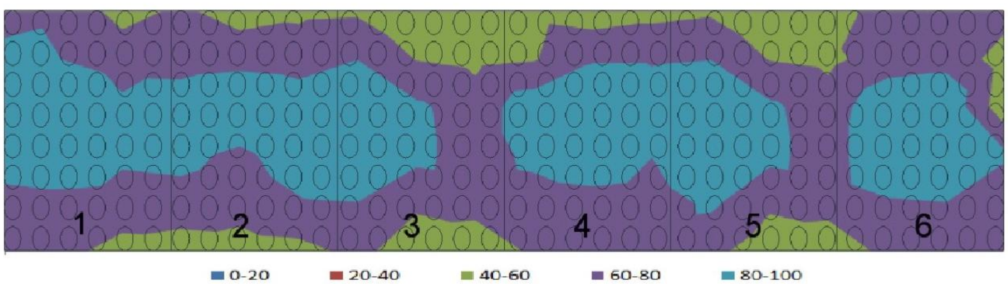

Figure 4. Water distribution on the 6x1 m surface

For the rainfall intensity of 3.1 mm/min, the value of the uniformity coefficient is 0.80. Since the rainfall intensity is regulated by the time the nozzle is kept in the side position, it is reasonable to assume that the water distribution over the surface would follow the same pattern for other intensities as well.

4. DISCUSION AND CONCLUSIONS

For the constructed rainfall simulator, based on oscillating nozzle, Christiansen's uniformity coefficient is calculated and its uncertainty is assessed. Simulator uses six VeeJet 80100 nozzles, manufacturer Spraying Systems Co., which were placed at height of 4.5 m and operating at a pressure of 40 kPa. Used nozzles, operating pressure and distance from the ground are consistent with the similar simulators found in the literature.

To achieve the intensity of a natural rainfall, it was necessary to block the nozzle spray with the box and to oscillate the nozzle above it. Maximum rainfall intensity achieved by this simulator is 3.1 mm/min.

The footprint of the same type of nozzle, from the same manufacturer and at the same operating pressure is not constant. By dividing the area into six equal parts, each of 1 m^2, value of Christiansen's uniformity achieved coefficient is 0.82 ± 0.031.

For the area size of 6x1 m, Christiansen's uniformity coefficient has a value of 0.80, which is in the range of measuring uncertainty.

Further research should focus on testing a larger number of nozzles with similar spraying effects to find the optimal one with best value of the uniformity coefficient.

ACKNOWLEDGEMENT

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ПРОЦЕНА НЕОДРЕЂЕНОСТИ КОЕФИЦИЈЕНТА РАВНОМЕРНОСТИ СИМУЛАТОРА КИШЕ

Rezime: *У протеклих шездесетак година развијено је неколико метода за оцену равномерности кише по површини али је метода коју је предложио Christiansen највише коришћена. У зависности од типа симулатора, типа млазнице и величине површине, Christiansenov коефицијент варира од 0.6 до 0.95. У овом раду приказан је начин одређивања Christiansen-овог коефицијента равномерности и процена његове неодређености услед мерних несигурности коришћене опреме. Овим симулатором могуће је симулирати интензитете кише до 3.1 mm/min са коефицијентом равномерности до 0.85.*

Кључне речи: *Коефицијент равномерности, симулатор кише, несигурност*