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Simulation of Watercourse Direction on Underlying Surface of Slope Lands

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***Abstract*—The author of the article considers that the water flow direction changes depending on the rate of the flow moving on the studied surface. The technology for simulating a watercourse direction on the underlying surface using the source method was developed. According to the results of the processed data the Cobb-Douglas-type nonlinear multiplicative function with the highest determination coefficient of 0,721 appeared to be the most accurate one for describing the erosion process. The analysis of the dependence obtained shows that with the water flow rate change by an average 1 %, the deflection angle of the water flow direction increases by an average 4,24% and the deflection angle of the water flow increases by an average 1,32% with the water rate increase by 1%.**

***Keywords*—simulation, watercourse, surface, lands**

I. Introduction

Water erosion of soil of slope cultivated lands is the most common and dangerous type of their degradation. Erosion greatly affects the reduction of both soil fertility and crop yield, and the structure of the soil continuum becomes worse as well. In cultivating crops on slopes cut by erosion scars and ravines the implementation of the technological process goes wrong that reduces the stability of anti-erosion machine running and its performance thus, resulting in quick wear of the machine [1, 2, 3]. Besides, both paved and farm roads are destroyed.

Considerable attention was paid to the problem of surface retention since its solution makes it possible to control watercourse formation in implementation and control of anti-erosion technologies on slope cultivated lands [4]. Many methods to evaluate the anti-erosion technologies have been developed both in our country and abroad, but not all of them conform to the current erosion processes [5, 6].

This can be explained by the fact that not all of soil features were properly taken into account.

These soil features of slope cultivated lands vary significantly, and the hydraulics of the slope runoff has its basic features as compared, for example, with those of river processes. Thus, certain scientific, methodical and technical difficulties can occur [7, 8, 9].

Any underlying surface that has roughness can be characterized by the hydraulic roughness coefficient, and its change in space can be represented by isoline maps. The representation of the hydraulic roughness coefficient in the form of isoline maps is in fact an equipotential surface [10, 11, 12, 13].

II. Materials and methods

Development of simulating methods for water flow control on slope lands in order to reduce erosion processes is an urgent problem studied by many researchers in our country and abroad [14]. The existing methods, in the main, require the use of schematic solutions and indistinct hypotheses. Applying these sorts of methods we can obtain equations, solve them and get a result that will demonstrate significant differences between the studied and the real processes [15, 16].

Therefore, to study the watercourse rate and its direction on the underlying surface at first approximation, the experimental method allowing information about the object to be obtained is the most relevant.

When studying a number of different physical phenomena and processes, the source method is used [14]. The principle of the method is as follows: the tested material is irrigated by a source (stream, linear or plane) which data are known. Then its impact on the material is analyzed according to the available information.

Simulation of the watercourse direction on the underlying surface was carried out using a device developed at the FSBEI HE Chuvash State Agricultural Academy [17]. A source is simulated as a water stream running at a certain rate that interacts with the surface having specified characteristics.

Figure 1 shows a principle scheme, and Figure 2 shows a general view of the device for simulating a watercourse direction on the underlying surface.

The device consists of a frame 1 and a removable slope tray 2, pivotally mounted on the frame 1.Water is supplied to the slope tray 2 by a Mariott Vessel 3 with a pipe and an attachment 4.

There is a pipe providing a constant water rate and a nozzle that allows the water to flow out of the vessel. At the lower edge 2 of the slope tray there is a collection vessel 5 for water drain.

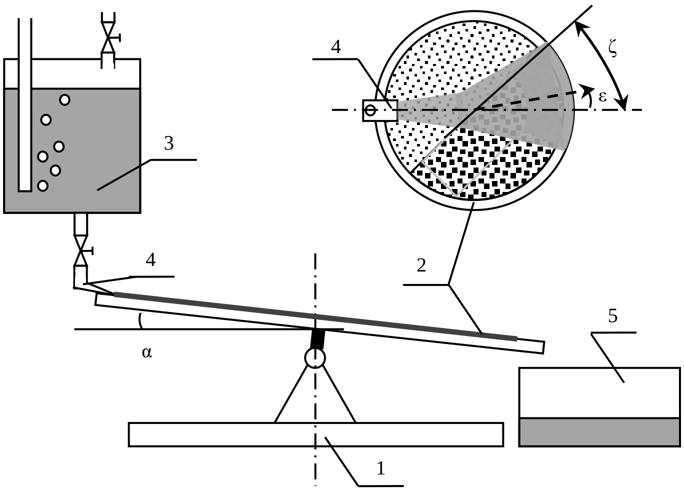

Fig. 1. The scheme of the device for simulating a watercourse direction on the underlying surface.

To make the specified rough surfaces in the laboratory, sand of the studied fraction is glued to the glass tray. Using a sieve method for separating particle fractions of various geometrical sizes, we divide sand into the fractions of specified parameters. Groups of sand fractions which diameters correspond to those of water-stable soil aggregates that are commonly found on the studied slope cultivated lands are selected.

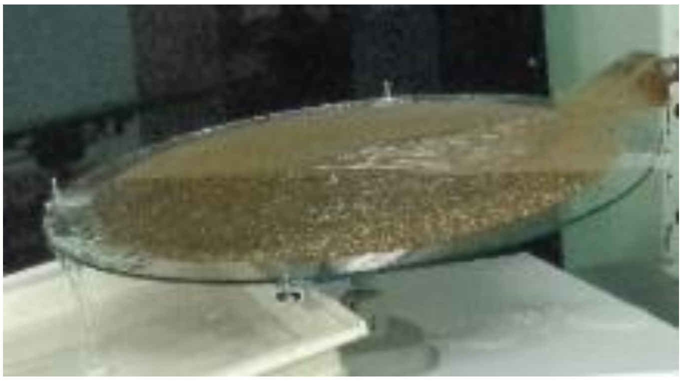

Fig. 2. General view of the device for simulating a water stream direction on the underlying surface

When the specified surfaces are prepared according to the above sequence of steps, the experiment is ready to be performed.

The slope angle of the tested surface α is set and due to rotation of the slope tray 2, the angle of deflection from the longitudinal axis ζ of the equipotential surfaces having a constant hydraulic roughness coefficient is set as well. We use Mariott Vassel 3 to regulate and set the water rate. The depth of the water stream at the lower edge 2 of the slope tray is determined by a micrometer, with the help of the needle 2 mounted on it (not shown).

Water rate, flow rate, height and width of the water stream at the lower edge of the slope tray and the deflection angle of the watercourse direction relative to the longitudinal axis are determined during the experiment. The direction of the watercourse and its deflection from the longitudinal axis are studied by measuring the linear dimensions of the water stream. Photographs taken parallel to the surface in certain time fractions are also used. The obtained results are recorded into the record book.

Thus, a technique for simulating a watercourse direction on the underlying surface of slope cultivated lands by the source method has been developed.

III. Results and Discussion

The study of the water stream direction on the underlying surface using the source method was carried out in the laboratory (Figure 3). The sand was previously sieved to create rough surfaces to be studied. Sand of different roughness was glued on to each glass sample that in its tern was put on a removable slope tray. It was possible to rotate the tray and set the angle ζ to the water stream direction.

The results of the experiments are presented in Figures 4, 5, 6 and in Table 1.

According to the results of statistical processing, which give a more real description of the process, the nonlinear Cobb-Douglas-type multiplicative function (R^2 = 0.721) turned out to be logically understandable and is expressed as for given conditions (angle of samples with a rough surface on the tray) to the water stream direction - 38 ° and the transition from the surface with a roughness of 0.2 mm to 1.6 mm):

$$\varepsilon = 9311{,}712\, Q_в^{\,4{,}23824}\, \upsilon_в^{\,1{,}32195}\,. \qquad (1)$$

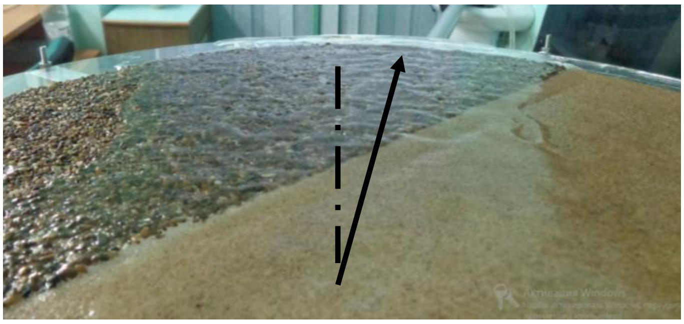

Fig. 3. Water stream deflection from the longitudinal axis of the studied surface.

Fig. 4. Deflection angle of the watercourse ε from the longitudinal axis at an outflow rate 29 cm / s

The analysis of the obtained dependence (1) shows that when the water rate changes by an average 1%, the deflection angle of the water direction will increase by an average 4.24%, and increasing the water rate by 1%, the deflection angle of the water direction will increase by an average 32%.

TABLE I. THE RESULTS OF THE EXPERIMENTS TO DETERMINE THE WATER STREAM DIRECTION ON THE UNDERLYING SURFACE

№	Slope angle of the tray α, degree	Angle of samples with a rough surface on the tray) to the water stream direction ζ, degree	Water rate $Q_{в}$, cm^3/s	Water flow rate out of the vessel $\upsilon_{в}$, cm/s	Deflection angle of the watercourse direction relative to the longitudinal axis ε, degree
1	3±0,5	38±0,5	12,3±0,1	19,83±1	12±0,5
2	3±0,5	38±0,5	13,6±0,1	21,93±1	10±0,5
3	3±0,5	38±0,5	15,7±0,1	25,32±1	7±0,5
4	3±0,5	38±0,5	16,3±0,1	26,29±1	6±0,5
5	3±0,5	38±0,5	17,2±0,1	27,74±1	5±0,5
6	5±0,5	38±0,5	12,8±0,1	20,51±1	11±0,5
7	5±0,5	38±0,5	14,1±0,1	22,62±1	9±0,5
8	5±0,5	38±0,5	15,3±0,1	26,14±1	7±0,5
9	5±0,5	38±0,5	16,9±0,1	27,17±1	5±0,5
10	5±0,5	38±0,5	18,1±0,1	28,65±1	4±0,5
11	7±0,5	38±0,5	13,3±0,1	21,45±1	10±0,5
12	7±0,5	38±0,5	14,3±0,1	23,06±1	8±0,5
13	7±0,5	38±0,5	15,9±0,1	25,64±1	6±0,5
14	7±0,5	38±0,5	16,3±0,1	26,29±1	6±0,5
15	7±0,5	38±0,5	18,2±0,1	29,35±1	4±0,5
16	9±0,5	38±0,5	12,6±0,1	20,32±1	7±0,5
17	9±0,5	38±0,5	14,1±0,1	22,74±1	6±0,5
18	9±0,5	38±0,5	15,8±0,1	25,48±1	5±0,5
19	9±0,5	38±0,5	16,9±0,1	27,25±1	4±0,5
20	9±0,5	38±0,5	18,0±0,1	29,03±1	2±0,5

Fig 5. The deflection angle of the watercourse ε from the longitudinal axis at an outflow rate 25 cm / s

Fig 6. The deflection angle of the watercourse ε from the longitudinal axis at an outflow rate 21 cm / s

The experiments show that the values of the hydraulic roughness coefficient vary along the slope, i.e. with the direction of the watercourse [18]. Therefore, we can consider that the rate of the change of the hydraulic roughness coefficient on the studied underlying surface is equal to the scalar multiplication of the gradient hydraulic roughness and the unit vector of the water flow direction.

IV. CONCLUSION

Thus, the results of laboratory studies have shown that the direction of (the deflection angle ε of the watercourse from the central axis of the slope surface) varies with the water flow rate moving across the surface. As the water flow rate decreases, the dynamic axis begins to deflect significantly when moving from one equipotential rough surface to another that significantly affects the change of the watercourse direction as a whole.

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