Soil resistance in the process of dams' irrigation canals profiling

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Abstract. The questions of processing technology of dam channels using appropriate mechanisms are presented taking into account the requirements of modern engineering hydrology. Channel profiling with the best quality and performance can be carried out by means of mechanization at the expense of working tools, able to process not only longitudinal but also cross-sections of channels. According to calculations, there was established, that the best condition for moving soil on the channel slope in front of the passive knife, is an equable distribution along the slope. It was marked, that the strength of the soil pressure is most affected by the installation value of the trowel knife and the thickness of the loosened soil layer to be compacted. Recommendations on increasing the active working body stability of the dam profiler are given.

1 Introduction

Reclaimed lands are the main link in the agricultural production stabilization. Worldwide irrigated land area is about 270 million hectares, of which in India – 21%; in China – 17.7%; in the USA – 9.3%, and Russia accounts for 1.6%. In the world, the area of drained lands is – 200 million hectares, of which the United States owns a share of such territories 30%; China – 3.4%; India – 31%; Russia – 2.4%.

Today, only 1.5 million hectares of reclaimed land are effectively used. In Russia there are many regions with adverse climatic conditions. These are permafrost zones, mountain ranges and arid steppe zones. For example, the USA, where less than 400 mm of precipitation falls annually, is less than 2%, and in Russia – 40%, the share of 6 farmland with rainfall of 700 mm or more in the USA is 60%, and in Russia only 11%.

In the new land use conditions, many parameters of the further development of irrigation systems have been revised. The issues of irrigation systems technical level improving, the reliability and environmental friendliness of its work have come to the fore. The issues of irrigation systems operation, water supply and water distribution management are examined in a new way. [1-14]. Land reclamation, in general, and irrigation systems, in particular, are the most powerful environmental transforming factors and can lead to negative environmental consequences in this region.

Currently, for profiling the dams' surface of irrigation canals, planning works use machines that are not intended to perform these works, or machines that have low

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productivity. This direction is not sufficiently studied, therefore its relevance is not in doubt.

As a basic machine, we can take a machine with an optimal working width, equal to the dam cross section perimeter, since the most promising is the use of machines for profiling by increasing the working tool width. Such arrangement of profiler working tool, relative to the base machine is most successful, since the traction resistance during profiling will be evenly spaced. The scheme of channel dams' surface profiling by machines with working body symmetrical arrangement facilitates the constructive decision of the profiler and allows more efficient use of the base truck power.

In order to increase the speed of mechanization means movement for channel maintenance and increase canal repair machines productivity during deformation of the dam crest, scientific studies have been carried out to improve the working conditions of machines that reduce water loss from filtering due to channel profiling.

The main requirement for the newly created reclamation machines for the care of irrigation canals should be ensuring high productivity when processing canals' dams using various working tools, capable of processing not only longitudinal but also cross-sections of channels.

2 Theoretical studies

The surface of irrigation canals dams consists of horizontal section — dam crest and two inclined surfaces — external and internal slopes. In the ideal case, the above channel surfaces represent planes located at certain angles to the horizon.

Let us consider the uneven dams' microrelief to be aligned, in a plane, perpendicular to the surface under study and parallel to the longitudinal axis of the dam. Perfectly aligned surface in the measurement plane represents a straight line crossing the wavy microprofile in such a way, that the area of soil protrusions located above it, is equal to the area of depressions located below the line.

In this case, when leveling the surface with minimal energy consumption, it is necessary to move such an amount of soil, that the resulting surface is smooth, i.e. closely matched the perfect surface.

The average linear deviation from the absolute values midline of plot surface microprofile ordinates, measured at intervals $\Delta\ell$, is

$$\Delta h = \sqrt{\frac{1}{n} \sum_{i=1}^n (h_i - h_{cut})^2}, \quad (1)$$

where h_{cut} — midline ordinate, cm;

h_i — microprofile current ordinate, cm;

n — number of measurements.

Making an assumption, that the obtained microprofile of the surface of the channels in the studied plane is constant for a certain section of width B and length L we get

$$V_{cut} = V_{bf} = B \cdot L \cdot \sqrt{\frac{1}{n} \sum_{i=1}^n (h_i - h_{cut})^2}, \quad (2)$$

where V_{cut} — volume of soil to be cut, m^3 ;

V_{bf} – soil volume required for backfilling, m^3 .

Due to the fact that the soil has a high density before destruction, replace in the formula $V_{bf} = V_{cut} \cdot K_d$ and, making the necessary transformations, determine the volume of soil to be cut during alignment of the channel dam section

$$V_{cut} = \frac{K_d}{(1 + K_d)} \cdot B \cdot L \cdot \sqrt{\frac{1}{n} \sum_{i=1}^n (h_i - h_{cut})^2}, \quad (3)$$

analogically

$$V_{bf} = \frac{K_d}{(1 + K_d)} \cdot B \cdot L \cdot \sqrt{\frac{1}{n} \sum_{i=1}^n (h_i - h_{cut})^2}. \quad (4)$$

In the obtained formulas, the linear deviation average of the microprofile ordinates' absolute values from the midline of an arbitrarily selected section can be considered as a random process. Therefore, for practical calculations, it is more convenient to use the standard deviation of the irregularities from the midline σ_h^{cut} «typical» dams' surface, defined by set σ_h , i.e

$$\sigma_h^{cut} = \frac{1}{n} \sum_{i=1}^n \sigma_h^i, \quad (5)$$

where σ_h^i – standard deviation of the plot irregularities;

n – number of study sites.

In order to ensure minimum energy intensity of the dams surface leveling process, the geometric parameters of the equalizer working tool should be such, so that in the work process we can transport the minimum necessary amount of soil, the value of which can be determined

$$V_{pr} = \frac{K_d}{(1 + K_d)} \cdot B' \cdot \ell \cdot \sigma_h^{cut} \quad (6)$$

where B' – width of the surface, processed by working tool, m;

ℓ – length of drawing prism base, measured perpendicular to the cutting edge.

3 Results and discussion

Studies of microprofile irregularities of the channel dams' surface profile to be profiled have been conducted. These studies show that for both types of selected surfaces, the statistical parameters' average values of the studied dam surfaces, as well as parameters of the averaged correlation functions and spectral densities, obtained from the functions realizations ensemble describing the microprofiles irregularities of the channel dams studied surfaces, can serve as averaged statistical characteristics.

The revealed statistical characteristics of channels surface irregularities distribution represent direct material not only for the design of machines, and for:

- determining the soil volume that needs to be moved from high places to low ones when leveling dams surface;
- creating simulation conditions and operating modes in laboratory and experimental studies of channel-repair machines working tools;
- determining the basic geometric parameters of canal repair machines working tools;
- development of technology for the application and establishment of differentiated agrotechnical tolerances for operations performed by a complex of machines for irrigation canals care.

Taking into account the stated requirements, calculation of the resistance to passive and trowel knives movement and justification of dam profiler combined working tool parameters were carried out.

4 Passive knife movement resistance

With the steady process of profiling, the combined working tool passive knife of profiler moves a certain mass of soil G_h , necessary for swamping on dam troughs treated surface. Therefore, the force, required to determine the resistance forces to the movement of the passive knife will be spent on moving the loosened soil (Figure 1).

Fig. 1. Scheme for determining the resistance to movement of a passive knife.

On the crest of the channel dam (horizontal plane), the force will be equal

$$P_{sh} = G_h \cdot f_1, \quad (7)$$

where f_1 – soil friction coefficient.

The best condition for moving soil on channel slope in front of passive knife is its uniform distribution along the slope. In this case, on the channel slope, the force is

$$P_{ss} = G_h \cdot f_1 \cdot \cos \lambda, \quad (8)$$

where λ – slope pledging angle.

5 Resistance to trowel knife movement

The working conditions of the trowel knife are characterized by a negative cutting angle α_{sr} . After mashing process stabilization, the knife 1 compacts a layer of various soil on slopes by an amount h (Figure 2).

Fig. 2. Trowel knife installation diagram.

The force spent on compaction of loose soil R_{sr} by layer h , can be determined if we accept the assumption that the loosened soil layer resistance during crushing is proportional to the strain value (Figure 3). In this case, the normal pressures plot on the trowel knife working surface will have the shape of a triangle

Fig. 3. Scheme for the determination of soil pressure on the trowel knife.

Maximum ground pressure P at the point B is

$$P = K_{sr} \cdot h, \quad (9)$$

where K_{sr} – soil resistance to crushing.

Resultant R_{sr} of elementary normal pressures during compaction of loosened soil layer on the trowel knife working surface at the point B is

$$R_{sr} = \frac{\overline{AB} \cdot P \cdot b_{sr}}{2}, \quad (10)$$

where b_{sr} – trowel knife width.

Since $AB = \frac{h}{\sin \alpha_{sr}}$, and $P = K_{sr} \cdot h$,

so

$$R_{sr} = \frac{K_{sr} \cdot h^2 \cdot b_{sr}}{2 \sin \alpha_{sr}}. \quad (11)$$

Magnitude of force P_{sr} taking into account the trowel knife friction forces on the ground, it can be determined by assuming that P_{sr} deviated from normal force R_{sr} by angle φ (Figure 4).

Fig. 4. Scheme to determine the effort spent for crushing soil with a trowel knife.

$$P_{sr} = \frac{K_{sr} \cdot h^2 \cdot b_{sr}}{2 \sin \alpha_{sr} \cdot \cos \varphi}. \quad (12)$$

Vertical component P_{srz} and horizontal component P_{srx} of the resultant normal and tangential resistance forces due soil compaction with a trowel knife will be equal

$$P_{srz} = \frac{K_{sr} \cdot h^2 \cdot b_{sr}}{2 \sin \alpha_{sr} \cdot \cos \varphi} \cdot \cos (\varphi + \alpha_{sr}); \quad (13)$$

$$P_{srx} = \frac{K_{sr} \cdot h^2 \cdot b_{sr}}{2 \sin \alpha_{sr} \cdot \cos \varphi} \cdot \sin (\varphi + \alpha_{sr}). \quad (14)$$

From the last equation, it follows that by the magnitude of the force P_{srx} the most influence is exerted by the trowel knife installation value α_{sr} and the loosened soil thickness to be compacted.

It should be noted that it is possible to reduce the resistance to knives movement by applying solid lubricant coatings [15-29].

6 Conclusions

1. The necessary accuracy of channel profiling is provided when using machines capable of processing not only longitudinal but also channels' cross-sections.
2. The best moving soil condition on channel slope in front of the passive knife is its equable distribution along the slope.
3. The pressure magnitude is most affected by the trowel knife installation value and the loosened soil layer thickness to be compacted.
4. The developed materials can be recommended for use in the construction and operation of irrigation systems.

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