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Calculation of Local Water Behind the Lower Water Mountings

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ABSTRACT: The complex issue of local erosion on the deformable section of the downstream of hydraulic structures is considered. A methodology is proposed for calculating the parameters of the erosion funnel behind the tailwater fastenings.

KEYWORDS: tailwater, fastenings, deformation, local erosion, erosion funnel, erosion depth, jump, local speed, pulsation

I. INTRODUCTION

Currently, due to the complexity of the phenomenon of local erosion, there is no universal calculation dependence for predicting the parameters of the local erosion funnel behind the tailwater fastenings, which would comprehensively take into account the influence of all factors in this process. Existing schemes and dependencies give a significant scatter in the calculation results. In this regard, the formulation of the research problem in our work should be considered as an attempt to understand the complex issue of local erosion in the deformable section of the tailwater [2, 4, 11, 15].

II. METHODOLOGY

Let us dwell on the development and refinement of the methodology for calculating local erosion in the area behind the fastenings of structures , based on the experiments performed .

In general, local bottom erosion is a function of a large number of variables [1, 3, 110, 2,16,17,]:

$$h_p = f(q, g, \upsilon_0, \upsilon, h_0\sqrt{Q^z} \cdot l_{kp}, d, \rho, \alpha, t)\,. \tag{1}$$

The main variables are:

$$h_p = f(q, g, \upsilon_0, \upsilon)\,. \tag{2}$$

Denoting $\upsilon - \upsilon_0 = \upsilon_*$, “ υ_* ” in this case is an excess of erosive power.

Based _ π-theorem, dependence (2) can be written:

$$h_p = K_l, q^x, q^y V_B^Z\,, \tag{3}$$

where K_l is the dimensionless coefficient x, y, z and are the exponents. Using the dimensional analysis method, we can write:

$$h_p = K_l \frac{q^x}{g^{1-x}} \upsilon_*^{2-3x}\,, \tag{4}$$

and by introducing adjustments to the kinetic energy, taking into account not only the uneven distribution of velocities and their pulsation characteristics, one can obtain:

$$h_p = K_l \sqrt{\frac{\alpha' q}{g}(\upsilon - \upsilon_0)}\,, \tag{5}$$

where α' is the correction for the kinetic energy of the erosion funnel.

A similar relationship was obtained in [1] where the main variables were:

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$$h_p = f(q, g, \upsilon_1, \upsilon_2, f, t)\,. \quad (6)$$

B as a result of the transformations, a dependence was obtained;

$$h_{p(t)} = \frac{(\alpha_0\upsilon - \upsilon_0)^{1,7} h_0^{0,2}}{K(\rho^*)^{0,7}} - t_i^{0,4}, \quad (7)$$

Where $\rho^* = \frac{\rho_H - \rho}{\rho}$; t_i – time corresponding to the moment of erosion h_{pi} ; h_0 – depth of flow at the end of the fastening; α_0 - coefficient of uneven distribution of speeds and intensity of pulsations.

The use of a computational scheme to determine the depth and focus of erosion requires careful experiments to study the dynamic structure of the spatial flow and the erosion funnel.

Therefore, we will focus on clarifying dependence (7), which allows us to predict local erosion over time and an analogue of formula (5) [2 , 3, 4, 9, 13] :

$$h_p = K_1 \sqrt[1,2]{\frac{K_2 q}{\upsilon_0}}\,. \quad (8)$$

The causes of local washouts that occur in the downstream reaches of dams are an increase in the erosive ability of the flow due to incomplete damping of excess flow energy within the fastening and the uneven concentration of specific flow rates along the width of the spillway front [2, 4, 8, 16].

One of the ways to extinguish excess energy is to have a submerged jump on the spillway under any possible operating modes of the spillway.

A flooded jump is characterized by the presence of a surface roller, bordered on top by a curved surface ABC (Fig. 1), and below by a sharply expanding transit jet (see solid lines in Fig. 1).

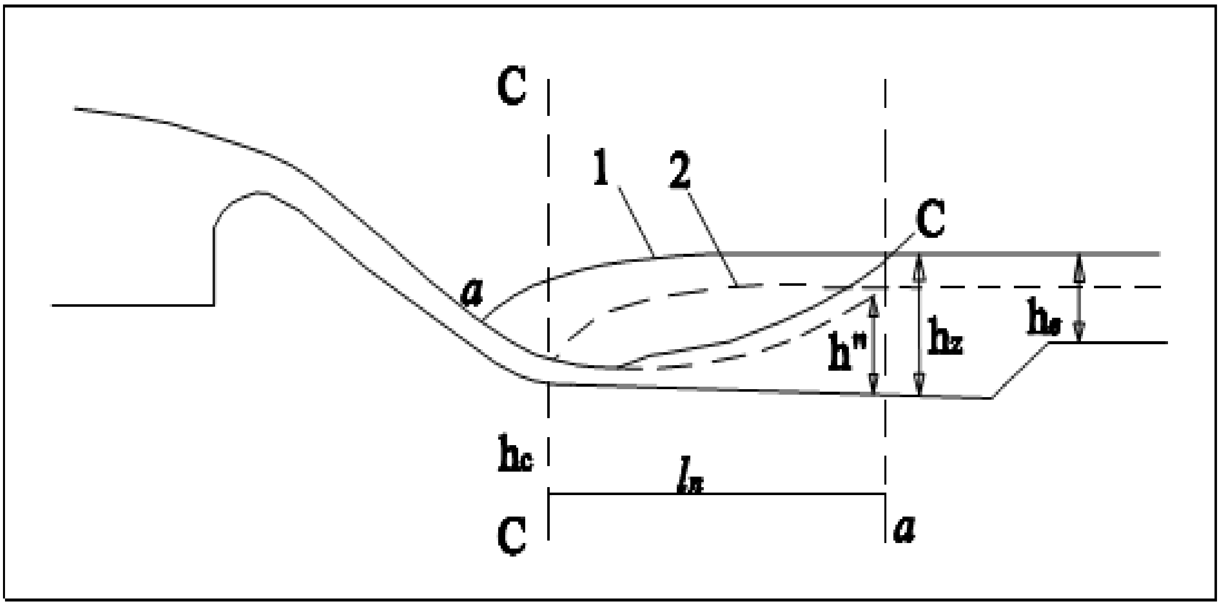

Fig.1. Dam Jump
1 - flooded jump; 2 - jump in a compressed section C-C

Experiments show that with the degree of flooding of the jump $A = h_2 / h_z \approx 1,0$ the surface roller of the jump has a particularly unsteady position: it makes constant translational movements, now to the left, now to the right (see Fig . 2), and the fastenings of the lower tail are subject to variable load.

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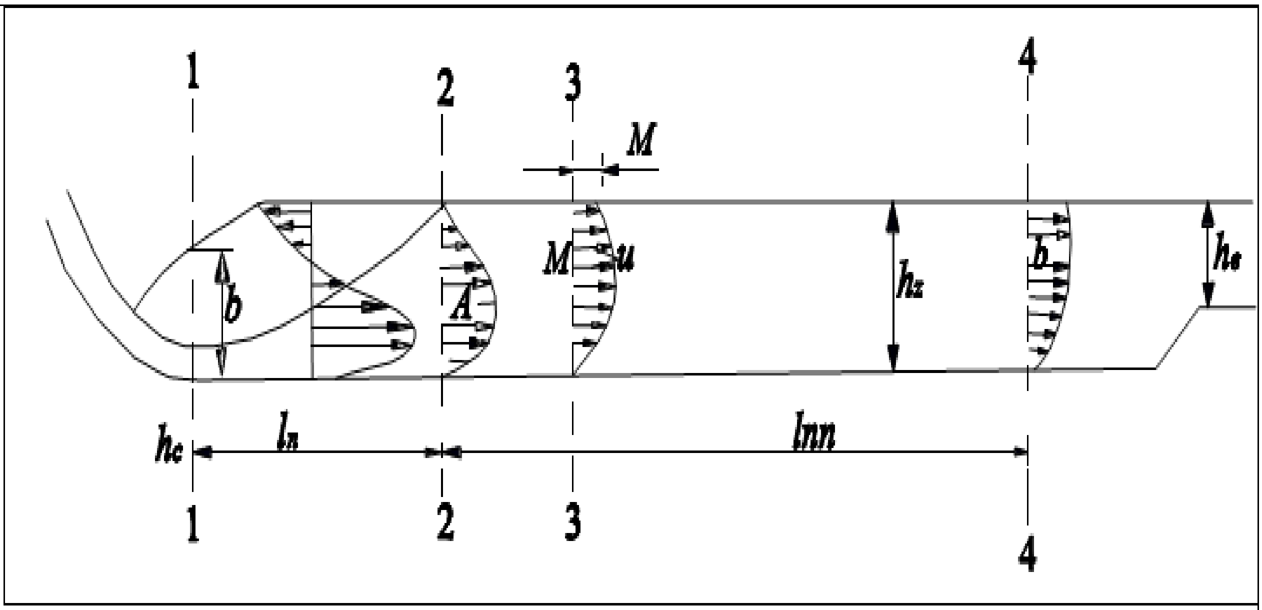

Fig.2 . Deformation of the average velocity diagram along the post-jump section

However, it is unprofitable to increase the degree of flooding of the jump unnecessarily (for economic reasons). It is usually assumed that 1.05,...1.2.

It is on this value A that the jump is calculated at the designated marks of the water surface.

In the literature, however, there are indications that in the presence of spatial conditions for the flow of the downstream flow, the value A should be taken approximately equal to 1.3.

When calculating turbulent flow, one usually operates with longitudinal time-averaged velocities at individual points of the flow. Such longitudinal velocities (diagrams) are shown in Fig. 2 for various vertical sections of the flow.

Longitudinal time-averaged velocity u at a given fixed point M in space can be explained using a graph of the pulsation of actual (current) longitudinal velocities u_a, time-variable (Fig. 3) . as can be seen from the graph

$$u = u_a - u',$$

where u' is the pulsation longitudinal velocity or pulsation addition, and $u' \prec 0 \text{ или } u' \succ 0$.

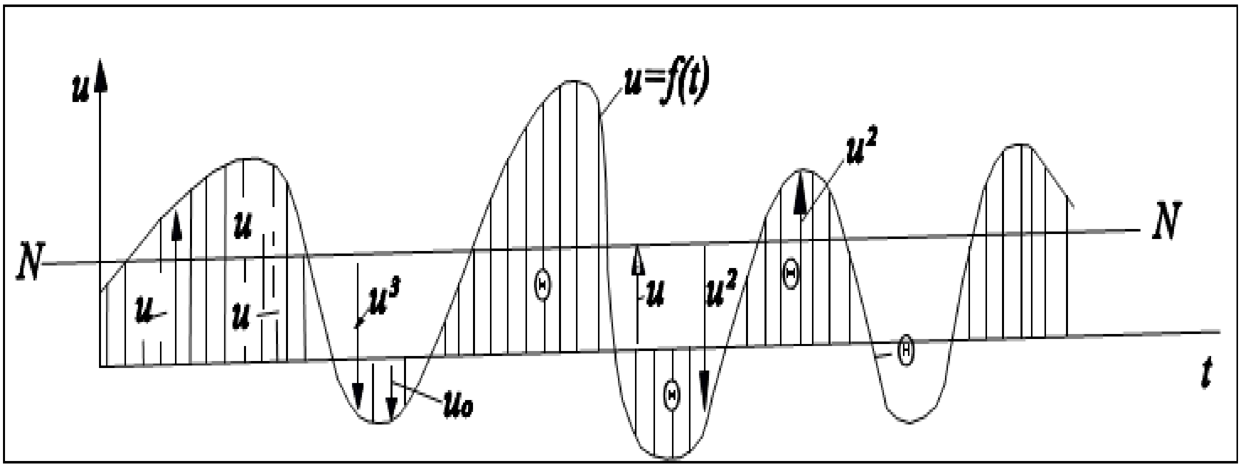

Fig.3. Scheme of the pulsation graph of the longitudinal actual speed (for a given fixed point N of space)

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If M there were no pulsation in this one, i.e. $u_M = 0,\ u = u_0$, then the specific kinetic energy at this point turns out to be equal $(KЭ)_{u=0} = \frac{u^2}{2g}$ in the presence of pulsation at a given point M, the specific kinetic energy at this point turns out to be equal to $(KЭ)_{u=0} = \alpha_n \frac{u^2}{2g}$, where α_n is a coefficient $(\alpha_n \square\ 1)$ that takes into account the intensity of turbulence at a given point.

The specific kinetic energy averaged for a given open section can be represented as:

$$(KЭ)_{u=0} = \alpha_c \frac{\upsilon^2}{2g},$$

Where υ - the average speed in the section under consideration α_c is a generalized coefficient that takes into account two different factors: the unevenness of the distribution of speeds υ across the section χ and the intensity of pulsation of the actual speeds u_a at individual points of the section; size $\alpha_c = \alpha + \alpha_n$.

The value α_c will change along the length of the jump and the post-jump section due to α a decrease in the intensity of turbulence, therefore, at the same average speeds υ for different sections of the post-jump section, we obtain different values of K.E., and , consequently, different values of local erosion.

Below are the results of some experiments to determine the maximum depths of local erosion behind fastenings with a short and long apron (Table 1).

Table 1
Experimental data

Experiences	24	21	33	32	34	4	3	23	2
α_n	2.21	2.12	2.16	2.09	2.05	1.36	1.89	1.88	1.61
$\upsilon,\ m/s$	0.25	0.3	0.23	0.30	0.30	0.42	0.40	0.36	0.40
ℓ_n / ℓ_{kr}	0.13	0.33	0.5	0.50	0.37	1.00	1.10	1.27	1.30
h_2, m	0.07	0.079	0.053	0.052	0.036	0.037	0.020	0.045	0.015
h_p, m (experience)	0.19	0.164	0.110	0.13	0.095	0.230	0.170	0.150	0.080
h_p, m (ras)	0.093	0.170	0.109	0.132	0.105	0.227	0.173	0.157	0.078

From a series of experiments with fine-grained non-cohesive material for the tailwater, the duration of erosion stabilization was established to be t ≈2 hours a . The values of the maximum calculated erosion depths were determined by relationship (7) [1].

A hydraulic jump dramatically changes the structure of the flow located behind it; thanks to this, the post-jump section, characterized by some speed υ, turns out to be sharply different in the nature of the movement of water from a uniform flow, characteristic of the same average speed υ.

Directly after the jump in section 2-2 (Fig. 4) we get the following:

a) Diagram A of averaged velocities is characterized by higher bottom velocities than Diagram B, therefore, at the same average velocities, υ the erosive ability of the flow cross-section. 2-2 will be significantly larger than, for example, in sections 4-4.

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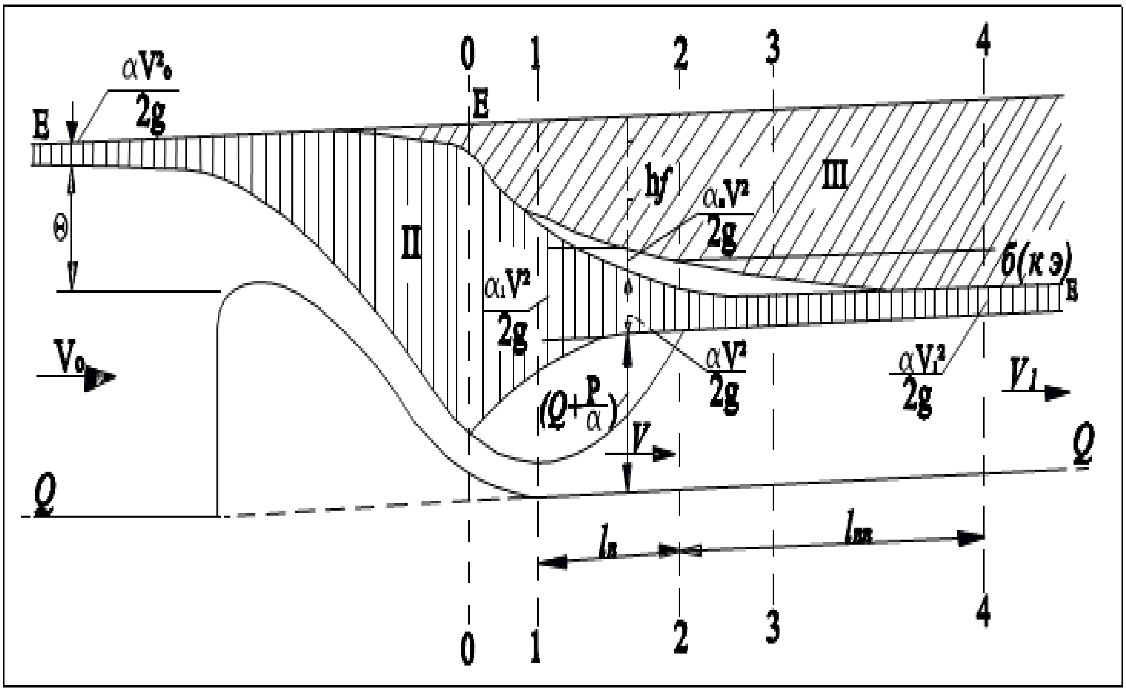

Fig.4. Qualitative picture of the extinguishing of excess energy in various areas of the body (according to D.I. Kumin) [14]

I – diagram of kinetic energy obtained from considering only averaged velocities (taking into account their uneven distribution over live sections); II – diagram of additional kinetic energy due to increased pulsation of speeds; III – pressure loss diagram.

Therefore, let us compare experiments 32 and 19 at $\alpha_c(2-2)\ u\ \alpha_c(4-4)$, i.e. $2{,}1 \prec 2{,}4$. Thus, when a jump propagates on a water jet, $\left(\frac{l_n}{l_{kp}} \leq 0{,}8\right)$ the magnitude of the coefficient of unevenness in the distribution of speeds and pulsation intensity, which results in a sharp and rapid expansion of the transit jet under the jump of the pulsation additive $u' < 0$ for many implementations, from here $\alpha_c < 2$ (see experiments 2, 3 and 23). Nevertheless, the magnitude of the erosion here is greater than when the jump is located within the aisles of the water hole (compare experiments 34-23). Based on processing the experimental results (Fig. 5), a relationship is proposed to determine

$$\alpha = 2{,}3 - 0{,}41\frac{\ell_n}{\ell_{kr}} \tag{9}$$

With the help of which you can determine the maximum erosion in time using formula (7).

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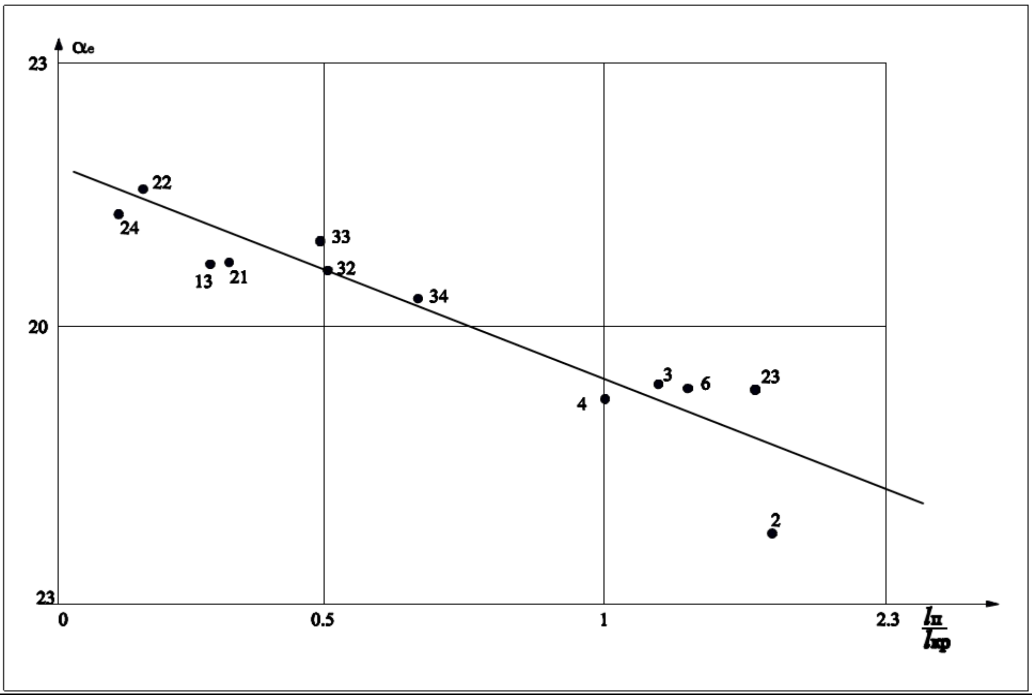

Fig.5. Addiction $\alpha = f\left(\ell_n / \ell_{kp}\right)$

However, the proposed method for short fastenings requires further inheritance and recommendations, because maximum local erosion is formed immediately behind the fastenings, and can be used only as an estimate in the general forecast of transformations for the tailwater.

The proposed calculation algorithm includes refined calculated dependencies that take into account the spatial conditions of the flow in the tailwater. At the same time, the range of numbers Fr_R was significantly expanded , the value of which reached Fr_R = 0.05-0.40. In this case, the main attention was paid to determining the parameter K.

At the same time, it was possible to somewhat expand the range of applicability of the dependence left in its structure, as in [5],

but for $Fr_R \le 0,40$

$$K_1 = 0,87 + 3,25Fr_R + 0,3M \; , \tag{10}$$

where $M = u'_{\max} / u$ is the flow turbulence parameter at the end of the apron or in the bucket.

For approximate calculations with a fastening length equal to 10-12 flow depths at the end of the apron, both in the presence of energy absorbers on the water body and in their absence, the value K_1, is taken equal to 1.2-1.3 [5].

However, the estimates showed that the value of K_1 is achieved according to K.I. Rossinki [3, 6], $K_1 = 1{,}05 - 1{,}7$ for a plane problem, according to B.I. Studenichnikov and I.I Taraimovich for spatial conditions up to 3 [8, 9].

The experiments carried out showed the possibility of using the structure of formula (10) to determine the coefficient K_1 for numbers, $Fr_R \le 0,4$ while the value of M should be determined according to the simplified one in the recommendations [58].

$$M = 0,2e^{2,1\frac{\ell_n}{\ell_{kr}}} , \tag{11}$$

where ℓ_{kr} is the length of the fastening from the compressed section to the section under consideration; e - the base of natural logarithms; ℓ_n - jump length.

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In the absence of flooding, the jump can be estimated using the formula $\ell_n = 5,7(h_2 - h_1)$, and in the presence of flooding, using the formula $\ell_n = 5,7(h_2 - h_1)$. According to our experimental results, the parameter M n e exceeded the values of 0.45 -0.50.

The maximum value of the coefficient K_1, according to our experience, is 2.30 - instead of 1.0-1.3 [5], taking into account spatiality gives K_2, it should be taken according to K.I. Rossinsky [7]:

$$K_2 = \frac{q}{q_0} = \frac{1}{2}\frac{\alpha_0}{\alpha}\frac{H}{h_0} + \frac{1}{4}\frac{B_0}{B}\left(1 - \frac{\alpha_0}{\alpha}\frac{H}{h_0}\right) + \left\{\frac{1}{4}\left(\frac{\alpha_0}{\alpha}\right)^2\left(\frac{H}{h_0}\right)^2 + \frac{1}{2}\frac{B_0}{B}\left(1 - \frac{\alpha_0}{\alpha}\frac{H}{h_0}\right)\left(\frac{\alpha_0}{\alpha}\right)^2\left(\frac{H}{h_0}\right)^2\left[\frac{1}{8}\frac{B_0}{B}\left(1 - \frac{\alpha_0}{\alpha}\frac{H}{h_0}\right)\right] + \frac{1}{2}\frac{\alpha_0}{\alpha}\frac{H}{h_0} + 1\right\} \quad (12)$$

Where B_0, h_0 - width and depth of the transit jet at the approach site (on the horizontal apron); B - total width of the tailwater; α_0, α - adjustments for the approach area and the erosion area.

If we take as a basis for calculating the total depth of water in the erosion funnel a formula that is easily derived from the condition of non-erosion velocities (8), then $K_{\max} = K_1 \sqrt[1,2]{K_2}$ it reaches values of 5. Numerous calculations have shown that the dependence is quite satisfactorily consistent with both our experimental data and those of a number of researchers, which allows us to recommend it for practical use.

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