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New small water passing structures at roads

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Abstract. A new type of a small water passing structures for roads is offered. Need of construction of new type small water passing structures is caused by the considerable height of a road bed in places of their construction that leads to unfairly high embankments on roads, big need for soil for construction, pits for production of soil and excessively high cost of construction of a road bed. If to proceed from need of new construction for Russia about 900 thousand kilometers of roads (at the general need of the country for a network of roads of national federal and regional value in 1.5 million kilometers, apart from local roads which it is necessary to construct about 850 thousand more kilometers), with a "brought by snow" height of an embankment 2 meters and the minimum width of a road bed on top 17.5 meters, will be required at least 35.1 cubic kilometers of the good soil suitable for a road bed. In article features of design of new type of a small water passing structures - "split" - type are stated. Theoretical calculations and data of hydraulic laboratory researches are submitted, and also recommendations about design of the offered small water passing structures of new type are provided.

Key words. Waterway, waterless valley, water throughput construction, expansion of a stream, expansion site length, stream speed.

1. Introduction

The crossing of small watercourses and dry land (temporary watercourses) by a road requires the construction of small-sized discharge facility—small bridges, culverts and other types of road hydraulic structures. Their number is great not only on a crossed, but also on a flat terrain—at least one per kilometer of road. In the design process, the control points of the project line position are determined concerning a longitudinal road profile [1–3]. The construction of roads in embankments requires a huge amount of soil and a variety of soil quarries [3, 4]. Therefore, it is necessary

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to look for the ways reducing the height of mounds on flat areas. One of them is the construction height decrease of a roadbed at the location of small culverts.

The main advantage of such construction is the possibility of control point location height decrease to design the longitudinal profile and, as a consequence, the reduction of a road-bed height, up to its construction "in zero marks" (see Table 1).

Table 1. Possible changes in an embankment height and the amount of imported soil for the construction of an embankment on the sections of the Moscow-St. Petersburg road

Road parameters and construction indicators	Moscow-St.Petersburg road				CRR	
	km 549–556.5		km 562–572		km 7–10, 31–35	
	Project	Proposed	Project	Proposed	Project	Proposed
Mound length (m)	7500	5175	10000	7385	4849	3860
Length of notches (m)	0	2325	0	2615	2151	3140
Average working mark of a roadway top (m)	2.61	0.07	2.47	0.51	1.01	0.64
Average working mark of the roadbed top (m)	1.67	–0.87	1.53	–0.43	–0.03	–0.37
Pavement thickness (m)	0.94	0.94	0.94	0.94	1.04	1.04
Average depth of a notch (m)	-	0.16	-	0.11	1.99	1.90
Volume of soil for embankment (thousand (m)^3)	438.375	154.390	612.095	195.435	736.882	438.637
Volume of soil from excavations (thousand m^3)	0	161.780	0	204.180	193.036	266.162
The volume of imported soil (thousand m^3)	438.375	0	612.095	0	543.846	172.475
The removal of soil from a construction site (thousand m^3)	0	7.390	0	8.745	0	0
Number of zero marks (piecess)	0	19	0	30	12	15
Number of discharge facilities (piecess)	7	2	4	3	9	6
The length of cuvettes (m)	7500	9462	7500	9462	5462	8650

Note: The number of culverts has decreased due to the change of surface water runoff scheme.

The return effect is possible–a "road" becomes the supplier of soil (from depressions and lateral drainage ditches) to construct embankments at the intersections of deep logs and other low relief areas.

The change of a small culvert design principle requires certain changes in the construction associated with the hydraulic pattern of a water flow. In this case, the leading log located near the roadbed of the road requires a culvert expansion to the desired width. The decrease of the culvert height is limited by the requirements of its cleaning possibility from the deposits from a water stream. Small longitudinal slopes of small logs in combination with the presence of vegetation reduce the speed of water flow and, thus, the carrying capacity of the water flow. Large pollution in accordance with the rules of small culvert operation (maintenance) should be removed by the road maintenance service [5]. Thus, a minimum height of a culvert can be set in the range of 0.3–0.4 m.

2. Research method

An extended discharge facility can work in a non-pressure (preferably) or in a pressure regime. The latter is worse because of backwater and roadbed flooding emergence, the in-crease of water flow at the exit from the structure. On the widening section of the log, the water flow spreads with a simultaneous decrease of its depth and flow velocity, since the flow rate of the water flow remains constant one (see Fig. 1).

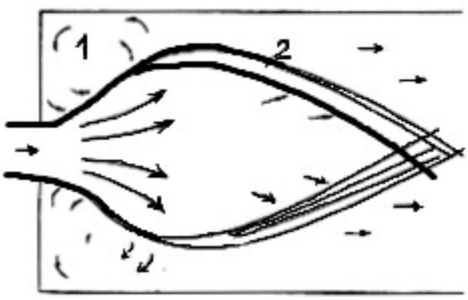

Fig. 1. Rapid flow spreading in wide channels: 1–whirlpool, 2–oblique hydraulics jumps

One can achieve a situation when the speed of the water flow reaches the value of "non erosive" for the soil. The length of a log section widening should be sufficient for a smooth expansion of a water flow to the magnitude of broadening.

With a sufficient degree of accuracy, the specific energy of flow E can be determined from the formula for the cross section of a water flow outlet from a natural log to an expansion site:

$$E = \beta h_{\text{out}} + \alpha V_{\text{out}}^2 \text{div } 2g \, , \tag{1}$$

where β is the coefficient of potential energy, taking into account the non-hydrostatic distribution of pressure in an outlet section, and h_{out}, V_{out} are the depth and the velocity of the water flow in an outlet section, respectively. At the form of a log channel part cross section, which is close in shape to a circular one (as in the case of a pipe), the coefficient β at non-pressure and channel filling $h_0/D = 0 - 0.5$ is assumed to be [0.5–0,6] (D is the diameter of an equivalent pipe and h_0 is the of flow in a log bed).

Like with the calculation of small bridges, the depth of the flow in the outlet section is determined from the Bernoulli equation. According to numerous studies the section of the surface water level reduction is formed before the cross section of the water flow outlet transits from the log to its widened part ($l_{\text{out}} = [3-4]h_{\text{out}}$).

For this section, neglecting (in view of smallness) the variation of a slope and the forces of friction within its limits, we can put down the following [2]. After the transformations, we get the final design formulae

$$h_1 + \alpha V_1^2 \text{div } 2g = \beta h_{\text{out}} + \alpha V_{\text{out}}^2 \text{div } 2g\,, \tag{2}$$

$$\eta_1 = \left[1 - \frac{\Pi\kappa_1}{2}\left(1 - \frac{w_1^2}{w_{\text{out}}^2}\right)\right]. \tag{3}$$

Here, $\Pi\kappa_1 = \alpha V_1^2 \text{div } gh_1$, the ratio w_1^2/w_{out}^2 is replaced by ratio $V_{\text{out}}^2/V_1^2 \times \eta = h_{\text{out}}/h_1$. Symbol w denotes the cross-sectional area of the flow in the corresponding section.

The values of h_1 and $\Pi\kappa_1$ for the slopes of the log $i_0 > i_k$ for the considered case are taken equal to $h_1 = h_0$, $\Pi\kappa_0 = Fr^2$ (taking into account a relatively large length of the log), where $Fr = V^2/(2g)$ is the Froude number for the section 1.

3. Results

When we calculate a flow spreading, we use the graph by I.A. Sherenkov (Fig. 2). We also determine $Fr_{\text{out}} = V_{\text{out}}/(\sqrt{g}h_{\text{out}})$ for the axis of the flow (X-axis). By means of Table 2 we find also the ratio XFr_{out}/b for the depths of the flow at a different distance from a cross section exit.

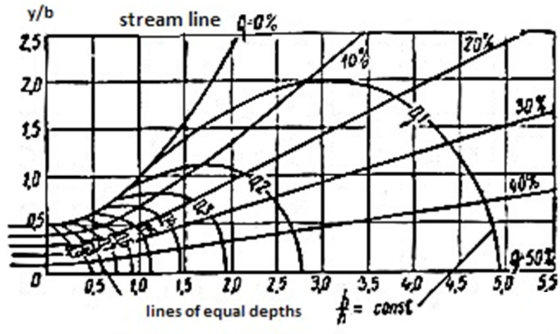

Fig. 2. The graph of current lines and the lines of equal depths

Table 2. The value of current line coordinates and the lines of equal depths (h/h_0) for the graph in Fig. 2.

Q (%)	Coord.	The lines of equal depths h/h_0 = const								
		0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0	$x/b\,Fr$	0.050	0.150	0.280	0.400	0.500	0.600	0.730	0.860	0.110
	y/b	0.503	0.510	0.530	0.565	0.620	0.675	0.760	0.870	0.100
10	$x/b\,Fr$	0.165	0.205	0.460	0.610	0.790	1.000	1.210	1.660	2.770
	y/b	0.405	0.420	0.450	0.500	0.575	0.690	0.820	1.110	1.980
20	$x/b\,Fr$	0.270	0.430	0.610	0.780	0.970	1.220	1.590	2.140	3.790
	y/b	0.310	0.330	0.360	0.410	0.480	0.580	0.750	1.020	1.840
30	$x/b\,Fr$	0.370	0.530	0.710	0.880	1.060	1.360	1.800	2.460	4.370
	y/b	0.210	0.230	0.250	0.290	0.350	0.440	0.560	0.770	1.360
40	$x/b\,Fr$	0.450	0.590	0.750	0.920	1.120	1.430	1.910	2.690	4.770
	y/b	0.115	0.125	0.140	0.160	0.190	0.230	0.300	0.410	0.760
50	$x/b\,Fr$	0.480	0.610	0.770	0.940	1.130	1.450	1.950	2.760	4.940
	y/b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: $Fr_{\mathrm{out}} = Fr_{zrmv}$, b is the width of the stream (the log channel) in the section of its exit to an expansion site, x is the distance along the flow, and y is the distance across the flow. .

At the outlet of a culvert, the width of a channel is equal to the width of its opening. The speed of water flow in a single-span structure is almost equal to the flow rate of water at an inlet. This speed is lowered due to a flow expansion. Therefore, no further spreading of a flow is required. With the corresponding soils of a log channel, the value of the non-eroding velocity can be achieved at the exit from a structure. For the purpose of flow spread visual estimation on the leading section of a log, an experiment was performed on a hydraulic tray. The scale of the geometric modeling is –1:2. The width of the supply channel was 0.60 m on the model; the speed of water flow in the exit section makes 0.860 m/s, the flow rate makes 0.01548 m^3/s. During the modeling according to the Froude model this is equivalent to a full-scale stream with the width of 1.2 m in an output section with the water flow rate of 1.216 m/s ($V_{\mathrm{M}}^2 = V_{\mathrm{N}}^2 \times h_{\mathrm{N}}/h_{\mathrm{M}}$) and the flow discharge of 1.459 m^3/s.

The length of the flow spreading section (l_{p}) was 1.05 m on the model, which corresponds to the length of 2.10 m for the natural flow. Thus, according to the dependencies shown on the graphs (Fig. 3), the length of the log channel expansion section before entering a small culvert should make at least the sum of distances $l_{\mathrm{p}} + l_{\mathrm{k}}$.

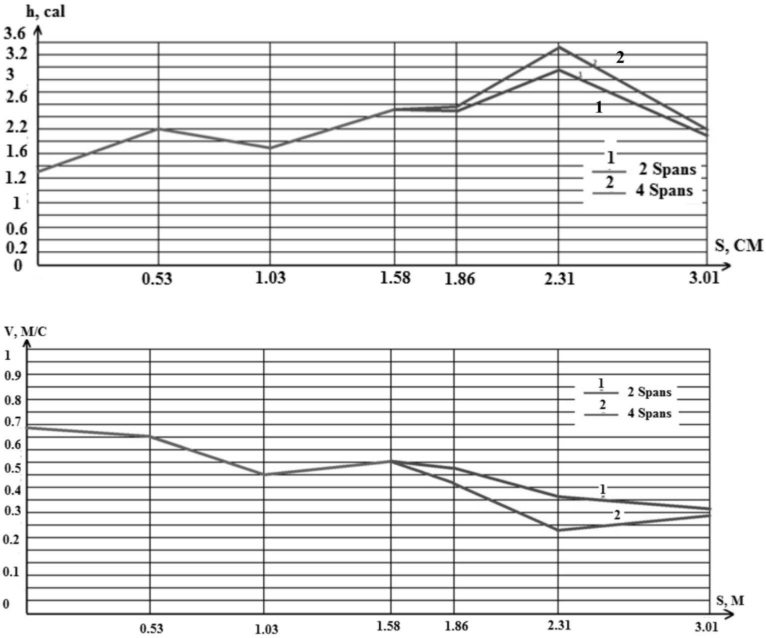

Fig. 3. Graphs of the level change concerning free surface of water and the flow velocity along the axis of flow on the area of its expansion

4. Conclusion

Theoretical and experimental studies allow us drawing the following conclusions:

1. A new principle is proposed for the construction of small culverts. the essence of which is to expand a channel on the way to a structure (instead of compression). This requires a hydraulic calculation of water flow parameters in each specific case. the collection of hydrological data on the development of a water flow during the flood period. conditioned by the need of a supply channel development (expansion).

2. The use of extended culverts in projects requires the revision of surface runoff diversion system flowing to a road: the usual construction of side drainage canals should be supplemented by the development of a spatial system for surface runoff receiving and discharging from the roadbed of a motor road; when such a drainage system is being developed on the territory adjoining a road, watercourses, dry valleys, and low places are fixed, where surface runoff can be redirected during the flood period instead of building a culvert on a plain.

3. The construction of small-sized extended culverts of water discharge facilities due to the reduction of their height allows to reduce significantly the need in imported soil for the construction of earthen cloth. which reduces the cost of a road building (Table 1).

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