



Research article
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Telescopic water intake with stilling well

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Abstract. Telescopic water intake structures have an important role in the water management system. Telescopic water intake has high mobility and wide field of application; at the same time, it is very simple and convenient to operate. But despite these advantages, there is no structural solution for flow energy dissipation in the downstream, no exact calculation method of flow energy dissipating structure, no structural solution to prevent floating objects entering inside the water intake structure, and no structural solution to stop water intake operation. In this regard, the purpose of this research is to improve the design of the existing telescopic water intake, to develop the design and calculation method for the stilling well. Structural solution for flow energy dissipation by means of stilling well is proposed. To protect the water intake from the ingress of floating objects and debris, protective mesh is designed. A shutter is provided to stop water intake operation of the unit. Methodology for analytical hydraulic calculation of a stilling well has been developed. In order to verify above mentioned calculation methodology, analytical calculations and numerical modeling of specific example were performed. The following results of analytical calculation of the main parameters of stilling well were obtained: length and depth. The results of numerical modeling demonstrated effective energy dissipation in the stilling well and acceptable flow velocity at the entrance to the channel.

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1. Introduction

In water management, water supply, energy and other areas of the economy, water intake structures with different designs and operating principles are used to draw water from different sources. In the vast majority, depending on topographic, geological and geographical conditions, frontal, side, bottom and tower intakes are used [1–11]. Each type of water intake structure has specific features and disadvantages. The main disadvantages of these water intake structures are the following:

1. When the water level in the sources fluctuates, their productivity (consumption) changes;
2. In springs filled with melt and spring waters, as well as waters of mountain rivers, the lower horizons have low temperatures compared to the upper ones. The water taken from these sources and supplied for irrigation has a detrimental effect on soil fertility and crop productivity. When the water temperature drops below 20 °C, the yield of agricultural crops in arid zones decreases by 30–40 %, and when the water temperature drops below 15 °C, agricultural crops completely die [12–15]. Along with this, when the temperature of the irrigation water drops below the temperature of the soil, its biological activity deteriorates, the process of nitrification and humification is disrupted;
3. When water is taken by known water intake structures, the purity and clarity of the taken water is not maintained, since during operation, suspended and bottom sediments are supplied to them.

In the middle of the last century in Japan, surface water intakes of various designs were developed under various names [16–20]. Analyzing the principle of operation and design features, as well as the

identified shortcomings of known surface water intake structures and devices, a new telescopic water intake device was developed [21].

Developed telescopic water intake contains a float, an inlet funnel, telescopically connected pipes tapering downward, an elbow with a discharge pipe and connecting elements. In order to prevent cavitation, a cone-shaped air supply pipe with a protrusion directed towards the inlet funnel is installed in the middle part of the float. To ensure the automatic movement of the float downward until the inlet funnel is closed in case of water absence (or liquid) or upon reaching a dead volume of water in the source, springs are installed in the lower part of the connecting elements (Fig. 1).

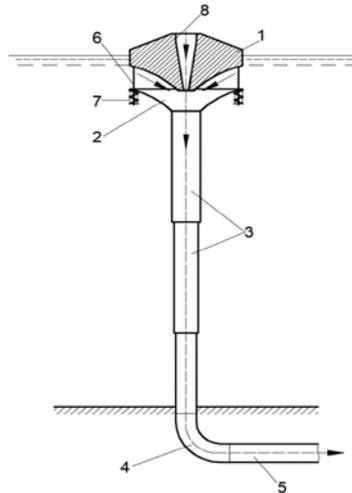


Figure 1. Construction of surface water intake:
1 – float, 2 – inlet funnel, 3 – telescopically connected pipes, 4 – elbow,
5 – outlet pipe, 6 – connecting element, 7 – springs, 8 – air-supply confuser.

The float, keeping the inlet funnel in the water immersed, provides a constant pressure at its inlet. In this case, water from the upper layers enters the funnel, and from there into the telescopically connected pipes, then through the elbow into the outlet pipeline.

When the water level in the source drops, telescopically connected pipes, funnel and float go down, and when the water level rises, they go up. Thanks to this, an automated water intake and a constant flow rate are provided, regardless of the effective pressure in the source. The water intake is carried out from the upper horizons, therefore, more clarified, cleaner and at the same time warmer water, heated by direct sunlight, enters the water intake.

When water enters the inlet funnel, the flow narrows and its speed increases, due to which vacuum and cavitation are formed. Air is sucked into the vacuum zone through the air supply pipe and the process of cavitation is prevented, characterized by the release of vapor-gas bubbles from the flow, causing crackling, noise and vibration, and ultimately erosion and destruction of the device. In the absence of water or reaching the dead volume in the source, the springs installed under the connecting elements ensure automatic closure of the inlet funnel.

Developed telescopic water intake has high mobility, wide field of application, at the same time, it is very simple and convenient to operate in comparison with known ones. Despite these advantages of water intake, it has several disadvantages. The telescopic water intake has high velocities at the exit from the outlet pipeline. In fact, when water is transported in an open way, i.e. by means of open canal, high entrance velocity to the canal leads to its erosion and destruction. The known device does not provide an element for stopping water intake in emergency situations, a stilling well for energy dissipation in the downstream and protective element to prevent floating and foreign objects from entering the inlet funnel, and then into the water intake. In addition, exact method for calculating a stilling structure is lacking.

In this regard, the purpose of this research is to improve the design of the existing telescopic water intake, to develop the design and calculation method for the stilling well.

2. Methods

In this research, structure of vertical telescopic water intake equipped with stilling well was analyzed by means of analytical calculations and numerical modeling [22–26].

If water intake is intended for water supply and transportation is carried out over long distances using a pipeline, then in this case there is no need for a stilling well.

When using a telescopic water intake, a sufficiently high working head is formed at the outlet of the outlet pipeline, and thus kinetic energy, which can be used to generate electrical energy by installing reactive electric turbine on the line at any convenient place in the outlet pipeline.

Thus, the water leaving the vertical telescopic water intake into the open channel at the outlet expands. The water leaving the diffuser gradually expands and at the end of the jet's flight reaches its maximum value. The jet expansion angle (θ_g) is equal to the diffuser taper angle (θ_d).

The diameter obtained at the end of the jet's flight can be taken as the depth of the water in the stilling well. In general, it is determined by the conjugate depth of the transporting channel [27, 28]:

$$a = h_2 - h_b, \quad (1)$$

where a is the depth of the stilling well (m); h_2 is conjugate depth (m); h_b is depth of water in the channel (m).

$$h_2 = D + 2L \operatorname{tg} \frac{\theta}{2}, \quad (2)$$

The length of the flight of the jet leaving the diffuser (L) is determined depending on the speed and acceleration of gravity by the following equation [11, 14]:

$$L = v \sqrt{\frac{2(Z + 0.5D)}{g}}, \quad (3)$$

where v is the speed of the jet leaving the diffuser, m/s; Z is the difference between the upstream and downstream pressures m; D is diameter at the outlet of the diffuser, m; $g = 9.81 \text{ m/s}^2$ is acceleration of gravity.

The velocity of the jet leaving the diffuser (v) is calculated using the following equation:

$$v = \frac{4Q}{\pi D^2}, \quad (4)$$

where Q is the water intake flow rate, m^3/s ; $\omega = \pi D^2/4$ is area of the outlet part of the diffuser, m^2 .

3. Results and Discussion

3.1. Analytical calculation

To prevent foreign floating objects from entering the water intake, cylindrical removable protective grid is installed around the connecting elements on the inlet funnel. To stop or regulate the flow rate of water taken from the source, a gate (valve) is installed in the downstream on the outlet pipeline, and a stilling well is built behind it to dissipate water energy [27] and prevent local erosion [30] (Fig. 2).

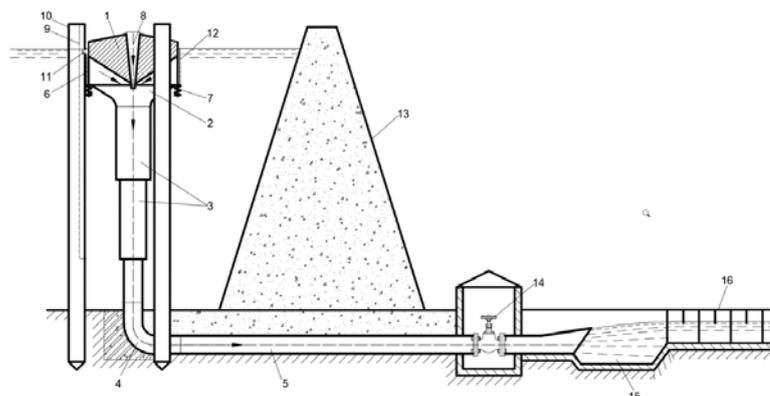


Figure 2. Scheme of telescopic water intake: 1 – float; 2 – entrance funnel; 3 – telescopically connected pipes; 4 – elbow; 5 – outlet pipeline; 6 – connector; 7 – release springs; 8 – air supply confuser; 9 – guide slot; 10 – piles; 11 – T-shaped ledge; 12 – lattice; 13 – dam; 14 – shutter; 15 – stilling well; 16 – channel.

The length of the stilling well is determined only by the length of the jet's flight. Therefore, the length of the jet flight determined by the equation (3) is taken as the length of the stilling well. Let us consider the hydraulic calculation of the proposed telescopic water intake using a specific example.

Example: Let us say the following parameters are set on the basis of the project:

- Estimated flow rate of the intake structure $Q = 10 \text{ m}^3/\text{s}$;
- The length of the outlet pipeline $l = 20 \text{ m}$;
- Difference of upstream and downstream pressures $Z = 10 \text{ m}$;
- Channel slope coefficient $m = 1.5$;
- Channel slope $i = 0.001$;
- channel roughness coefficient $n = 0.017$.

It is required to define the following parameters:

1. Diffuser diameter D ;
2. The diameter of the outlet pipeline d ;
3. Length of diffuser l ;
4. Parameters of the drainage channel, including the bottom width b and the water depth in the channel h ;
5. Average speed of water movement in the channel v ;
6. The depth of the stilling well a ;
7. The length of the stilling well L .

Solution. First, we take the system flow coefficient $\mu = 0.8$ and define the outlet diameter of the diffuser:

$$D = \sqrt{\frac{4Q}{\mu\pi\sqrt{2gZ}}} = \sqrt{\frac{4 \cdot 10}{0.8 \cdot 3.14 \sqrt{2 \cdot 9.81 \cdot 10}}} \approx 1.1 \text{ m.}$$

Now we take the value of the vacuum in the system $h_v = 6.5 \text{ m.w.s.}$ and calculate the diameter of the outlet pipeline:

$$d = \sqrt{\frac{4Q}{\mu\pi\sqrt{2g(Z+h_v)}}} = \sqrt{\frac{4 \cdot 10}{0.8 \cdot 3.14 \sqrt{2 \cdot 9.81(10+6.5)}}} = 0.94 \text{ m.}$$

We accept the taper angle of the diffuser 7° and calculate its length using the equation:

$$l = \frac{D-d}{2\text{tg}\frac{\theta}{2}} = \frac{1.1-0.94}{2\text{tg}\frac{7}{2}} = 1.33 \text{ m.}$$

According to [29], we determine the hydraulically most favorable radius of the channel.

In accordance with the slope coefficient of the channel $m = 1.5$, we determine the slope characteristic:

$$m_o = 2\sqrt{1+m^2} - m = 2\sqrt{1+1.5^2} - 1.5 = 2.106.$$

In accordance with the slope of the channel ($i = 0.001$), the flow rate ($Q = 10 \text{ m}^3/\text{s}$) and the slope characteristic of the channel ($m_o = 2.106$), we calculate the function of the most advantageous hydraulic radius using the equation:

$$F(R_{\Gamma.H}) = \frac{Q}{4m_o\sqrt{i}} = \frac{10}{4 \cdot 2.106\sqrt{0.001}} = 37.6 \text{ m}^3/\text{s.}$$

According to the tables given in the literature, for example [28] table A.16.6, in accordance with the values of the roughness coefficient $n = 0.017$ and $F(R_{\Gamma,H}) = 37.6 \text{ m}^3/\text{s}$, we find $R_{\Gamma,H} = 0.84 \text{ m}$.

With $\sigma = 1$, we determine the ratios $b/R_{\Gamma,H} = 1.40$ and $h/R_{\Gamma,H} = 2$. Whence $h = 2 \cdot 0.84 = 1.68 \text{ m}$ and $b = 1.4 \cdot 0.84 = 1.18 \text{ m}$.

We find free cross-section area of the channel by equation:

$$\omega = (b + mh)h = (1.18 + 1.5 \cdot 1.68) = 6.22 \text{ m}^2.$$

To determine the average speed of water movement in the channel from the above table No. P.16.6, we determine the value in accordance with the radius $R_{\Gamma,H} = 0.84$ and the roughness coefficient $n = 0.017$, $C\sqrt{R} = 52.67 \text{ m/s}$.

We determine the average speed of water movement in the channel by equation:

$$v = C\sqrt{R}\sqrt{i} = 52.67 \cdot \sqrt{0.001} = 1.67 \text{ m/s}.$$

We determine the bandwidth of the channel by the equation:

$$Q_k = \omega v = 6.22 \cdot 1.67 = 10.4 \text{ m}^3/\text{s}.$$

Control: The flow rate of the intake structure is $Q = 10 \text{ m}^3/\text{s}$, the throughput of the canal is $Q_k = 10.4 \text{ m}^3/\text{s}$, i.e. $Q_k \geq Q$. This means that the canal can transport the flow of water entering it with buffer.

To determine the depth of the stilling well, we determine the mating depth h_2 . For this purpose, using equation (4), we determine the water velocity at the outlet from the diffuser:

$$v = \frac{4Q}{\pi D^2} = \frac{4 \cdot 10}{3.14 \cdot 1.1^2} = 10.5 \text{ m/s}.$$

Then, using equation (3), we determine the length of the jet flight:

$$L = v\sqrt{\frac{2(Z + 0.5D)}{g}} = 10.5\sqrt{\frac{2(10 + 0.5 \cdot 1.1)}{9.81}} = 15.4 \text{ m}.$$

The jet expansion angle (θ_j) is taken to be equal to the diffuser taper angle ($\theta_j = \theta = 7^\circ$) and the mating depth (h_2) is determined by the equation (2):

$$h_2 = D + 2L\text{tg}\frac{\theta}{2} = 1.1 + 2 \cdot 15.4\text{tg}\frac{7^\circ}{2} = 2.95 \text{ m}.$$

The depth of the stilling well is determined by equation (1):

$$a = h_2 - h = 2.95 - 1.44 = 1.51 \approx 1.5 \text{ m}.$$

We accept the length of the stilling well equal to the length of the jet flight $l_q = L = 15.4 \text{ m}$.

3.2. Computer simulation

For computer modeling, ANSYS CFX software package was used. This module allows to solve complex hydraulic tasks.

A model of vertical telescopic water intake structure equipped with a stilling well has been assembled at a scale of 1:1. The initial dimensions for modeling are taken from the above given analytical calculations.

In order to perform hydraulic simulation, the same hydraulic characteristics and boundary conditions were used as in the above example.

Fig. 3 shows the diagram of the velocities distribution in the longitudinal section of the structure. This section cut was done along the center line of the structure.

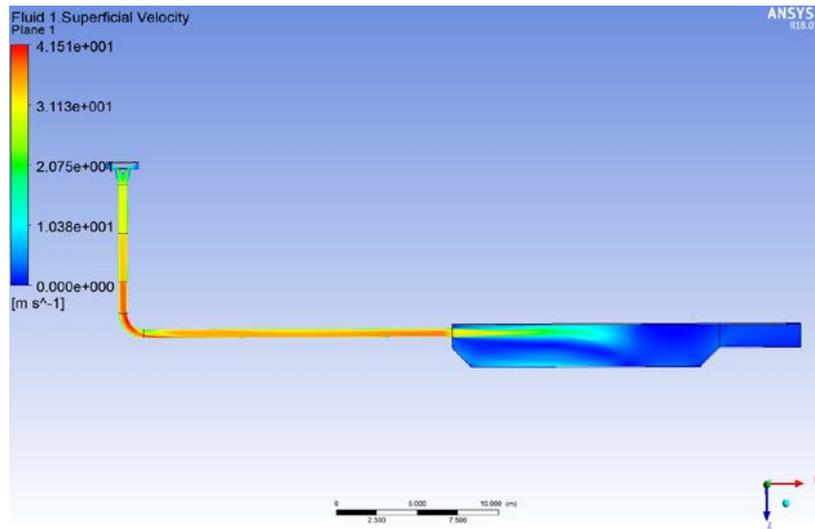


Figure 3. Diagram of water velocities distribution in the longitudinal section of the structure

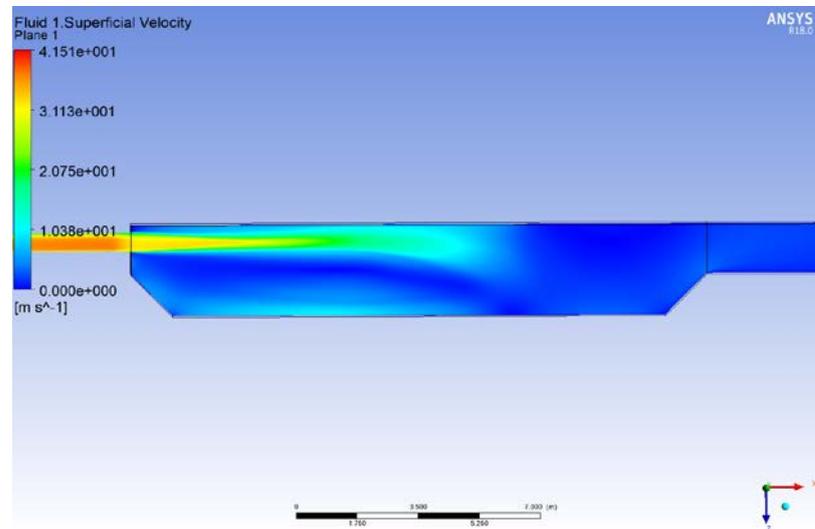


Figure 4. Diagram of water velocities distribution in the longitudinal section of a stilling well

The calculation results show that the maximum velocity in the outlet pipeline reaches 37 m/s (Fig. 3). In the diffuser, the flow expands and the speeds decrease. In (Fig. 4) it can be seen that the flow velocity at the edges of the diffuser is much less than in the center. Along the length of stilling well flow speed reduces and kinetic energy of the flow dissipates. At the exit of the stilling well, the speed is about 1.5–1.6 m/s. At the entrance to the main channel, the speed is 2 m/s.

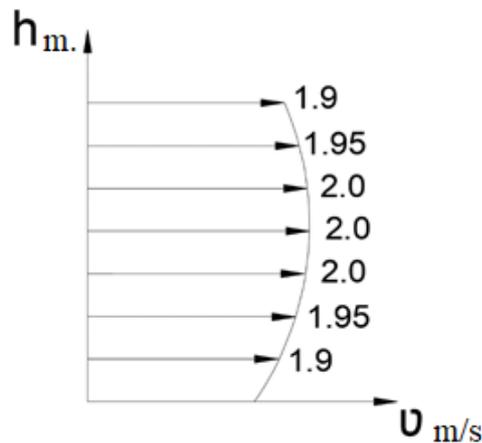


Figure 5. Velocity diagram in longitudinal section at the channel entrance:
 h – channel depth; v – flow velocity.

4. Conclusion

In this work, design of vertical telescopic water intake and energy dissipation of the downstream flow in case of transportation by means of open way were studied. The following main conclusions were obtained:

1. Protective mesh is proposed to prevent floating objects from entering inside the water intake.
2. A shutter is proposed to stop water intake operation.
3. Design of stilling well is proposed for energy dissipation in the downstream.

4. The main parameters of stilling well have been established and analytical method for its calculation has been developed. Results of analytical calculations were verified by numerical modeling. Velocity diagrams obtained from numerical modeling demonstrated effective energy dissipation in the stilling well.

5. As a result of numerical modeling, velocity distribution diagram at the entrance to the channel was obtained.

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