Hydraulic elevator for cleaning sediment of a water outlet of a reservoir

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Abstract. Many scientists of the world were engaged in the study and development of various schemes and models of hydraulic elevators for the purpose of excavation and hydraulic transport of hydraulic mixtures [1-22]. For the specific conditions of the selected research object, we determined the main sizes and parameters of the hydraulic elevator, which allows cleaning the water area of the bottom water intake of the spillway of the Tupalang hydroelectric station, using the hydrostatic pressure at the object concentrated in front of its dam. To clarify the particle size distribution of sediment deposited at the inlet head of the water intake of the Tupalang reservoir water outlet, samples of bottom sediments were taken and their particle size distribution was analyzed in laboratory conditions. At the water intake area of the 1st tier of the Tupalang reservoir, the deposited sediments are represented by smaller particles, the diameter of which is from 5 mm to 0.1 mm, and in percentage terms, their share is 95%. The main results are given for calculating and justifying the parameters of a hydraulic elevator for cleaning sediment from the water area of the inlet head of the water outlet structure of the first tier of the Tupalang reservoir. When determining and substantiating the main sizes of the hydraulic elevator, theoretical and experimental research methods were used, and the method of S.M.Shtin was applied.

1. Introduction
An analysis of the operation of the Tupolong hydroelectric complex (Surkhandarya region in Uzbekistan) showed that during its operation, a significant degree of siltation occurred in the reservoir bowl, and in particular the inlet part of the water body of the inlet head of the water outlet so that the water outlet works in very difficult operating conditions. In this regard, the operators urgently faced the need to develop recommendations on cleaning the sediment from the area of the inlet head of the first tier of the outlet structure, which is currently used both as a water intake for a hydroelectric power station and as a water intake for a water outlet structure. And also to improve the operating conditions of the inlet head of the first tier of the outlet structure, there was an urgent need to develop effective measures and methods for removing sediment from the water area of this structure.

The nature of sediment deposition in the upper pool of the reservoir mainly depends on the alluvial regime of the water source [1–7] on the operation mode of the structure itself and partly on the chemical composition of the water in the water source.

2. Methods
During the research, laboratory methods were used to analyze the particle size distribution for soils of the bottom sediment of the reservoir. When determining and substantiating the main sizes of the hydraulic elevator, theoretical and experimental research methods were used, and the method of S.M. Shtin was applied.

3. Results and discussions
The main purpose of our research was the justification and determination of the main parameters of a hydraulic elevator for cleaning sediment from the waters of the bottom water intake of the spillway of the Tupalang hydroelectric station.

To identify the morphometric composition of deposited sediments in the upper pool of the reservoir, it is first necessary to analyze the hydrological characteristics of the Surkhandarya river basin and its main tributary of the Tupalang River, which is the direct water source of the reservoir in question.

To clarify the particle size distribution of sediment deposited at the inlet head of the water intake of the Tupalang reservoir water outlet, samples of bottom sediments were taken and their particle size distribution was analyzed in laboratory conditions. Samples were taken on February 28, 2017 when leaving the research facility.

A detailed analysis of the particle size distribution of deposited sediments is given in table 1. An analysis of the composition of the deposited sediments shows that in the percentage ratio of 37% -38% are soils with a particle diameter of 0.25-0.10 mm. Soils with particle diameters less than 0.1 mm are in the percentage ratio of 15-16%. Then there are soils with particle diameters from 0.5-0.25 mm and in percentage terms, they make up from 14 to 15%. Summarizing these data, it can be noted that at the water intake area of the 1st tier of the Tupalang reservoir, the deposited sediments are represented by smaller particles, the diameter of which is from 5 mm to 0.1 mm and in percentage terms their share is 95%.

| Sample number | The total weight of the sample, g | particle size distribution in% to total weight |
|---------------|---------------------------------|---------------------------------------------|
| Sample #1     | 645.5, g                        | >10 mm 2.05; 10-5 mm 2.75; 5-2 mm 11.4; 2-1 mm 8.16; 1-0.5 mm 8.07; 0.5-0.25 mm 14.9; 0.25-0.10 mm 37.6; <0.1 mm 15.2 |
| Sample #6     | 684.7, g                        | >10 mm 12.3; 10-5 mm 18.5; 5-2 mm 82.4; 2-1 mm 54.7; 1-0.5 mm 53.6; 0.5-0.25 mm 97.6; 0.25-0.10 mm 264; <0.1 mm 101 |

Besides, the analysis of samples taken of bottom sediments shows that, with rare exceptions, there were small fractions of cleaved rock of irregular shape, the average diameter of which was 25-30 mm, descended from mountain ranges on the right side of the reservoir bowl. This is evidenced by a photograph obtained from the satellite, shown in Figure 2, this section is marked with a red line.

Summarizing the above, the following can be noted:
• The maximum particle diameter of bottom sediments is 25-30 mm;
• In percentage terms, the maximum proportions of particles of the soil of bottom sediments (95%) are particles with sizes from 5 mm to 0.1 mm.

To correct the calculated values of solid runoff, we used the data from the survey of the bowl, made by State unitary company “Batiometrik markaz” in 2003, 2007 and 2010. The measurement results are shown in Table 2.
Figure 1. The diagram of particle size distribution in% to the total weight.

Figure 2. Satellite view of the upper pool of the Tupolang hydroelectric complex.
Table 2. Actual siltation of the reservoir

| year | Number of years | For the period, million m$^3$ | For one year, million m$^3$ | Per interval |
|------|----------------|-----------------------------|-----------------------------|--------------|
| 2003 | 18             | 16.65                       | 0.92                        | 0.920        |
| 2007 | 22             | 20.35                       | 0.92                        | 0.917        |
| 2010 | 25             | 24.08                       | 0.96                        | 0.930        |

Measurement work carried out in December 2010 showed that a funnel with a diameter of 30–40 m along which water enters the head is adjacent to the head along the line of the spillway in the area of the head of the bottom mark within 824.0-824.5. The upper edge of the funnel has a mark of 830-831m. Water approaches a funnel along the developed channel, during compaction of which gravel-pebble deposits may approach or when the diameter of the funnel narrows, sand-clay deposits will flow there and a dense flow is possible.

The total amount of siltation for the period under review amounted to 24.08 million m$^3$. The existing useful capacity is 95.92 million m$^3$.

The most intense siltation occurred within 820.0-855.0. The total siltation in this interval is 21.30 million m$^3$, or up to 90% of all sediment in the upper range of marks (up to 891.0 m) silted up 3.08 million m$^3$.

All this shows that active siltation and entry occur within low grades, i.e. sediments are pulled to the dam. This situation is due to the mode of operation of the reservoir at low elevations. In this situation, the entry of the bowl with bottom sediments also occurs within the working interval of the tank.

The extension of the dam and the increase in the capacity of the bowl (i.e., increasing the length of the reservoir) will allow the sediment to be kept away from the dam.

With a reservoir volume of 380.0 million m$^3$, the morphometric characteristics of the flow will change (increase in bowl length, water depths, flow rates, etc.), which will lead to changes in transport conditions and sediment deposition. In this regard, sediment will begin to precipitate in areas farther from the dam, and only at low water levels will they begin to be pulled to the dam.

Under laboratory conditions, it is planned to simulate the process of cleaning the deposited sediment in the water area of the inlet head of the water outlet structure of the first tier of the Tupalang reservoir. To create a physical model for the study of hydraulic processes that occur during the washing off of deposited sediments, several designs of model plants are offered.

There are two methods for calculating hydraulic elevators, based on the theory of mixing two flows moving at different speeds; the theory of the spreading of a free jet in a mass of a liquid at rest[8 - 25]. At present, several experimental and theoretical works have proved that calculating a hydraulic elevator by the principle of mixing two flows more meets the real conditions of its operation than calculating by the theory of spreading.

It should be noted that when calculating a hydraulic elevator according to the first theory, it is impossible to determine the distance from the nozzle edge to the beginning of the neck Z. Therefore, to determine this size, it is recommended to use data from the theory of flowing, that is, from the second calculation method.

Based on these data, the basic structural dimensions of the hydraulic elevator can be determined with an approximate degree of accuracy, namely: nozzle diameter d$^0$; throat diameter d$^z$; the distance from the end of the nozzle to the beginning of the neck z.

3.1. The sequence of calculation:

a) Determination of ε
\[ \varepsilon = \frac{\gamma_p}{\gamma_w} = \frac{2.5}{1.0} = 2.5 \]  

(1)

Where: \( \gamma_p = 2.5 \text{ tonne } / \text{m}^3 \) is the pulp specific gravity  
\( \gamma_w = 1.0 \text{ tonne } / \text{m}^3 \) is the specific gravity of water

b) \( q_{op} \) value determination

\[ q_{op} = \frac{1 + \varepsilon}{(m-1)s} \left[ 1 + \sqrt{1 + \frac{3(m-1)s}{(1+s)^2}} \right] \]  

(2)

where: \( q = \frac{Q_s}{Q_c} \); \( Q_i = q_{op} \times Q_c \)

\[ V_i = \varphi \sqrt{2gh} = 0.85 \sqrt{2 \times 9.81 \times 100} = 44.3 \text{ m/sec} \]  

(3)

\[ \varphi = \frac{1}{\sqrt{1 + \xi}} \]  

(4)

Accept \( \varphi = 0.85 \).

We determine the coefficient of hydraulic resistance \( \xi \) according to the following formula:

\[ \xi = \left[ \left( \frac{d}{d_0} \right)^2 - 1 \right]^2 \]  

(5)

\[ m_{op} = \frac{2}{3} \left( 1 + \frac{1}{q} \right) \left( \varepsilon + \frac{1}{q} \right) \]  

(6)

3.2. Hydro Elevator Calculation:

Weight discharge of solid phase: \( Q_{s,ph} = 50 \text{ tonne/ hour} \)
Specific gravity of solid phase: \( \gamma_{s,ph} = 2.5 \text{ tonne } / \text{m}^3 \)
Volume Consistency: \( S = 1/5 \)
Pressure at the outlet of the hydraulic elevator: \( P_{s,ph,1} = 0.1 \text{ MPa} \)
Intake velocity: \( V_{int} = 5.0 \text{ m/sec} \)
Maximum diameter of solid particle: \( d_k = 10 \text{ mm} \)
Solid phase velocity: \( V_{s,ph} = 4 \text{ m/sect} \)

1) Determine the weight performance of intake slurry \( Q_{int} \):

\[ Q_{int} = Q_{s,ph} \left( 1 + \frac{\gamma_w}{\gamma_{s,ph,s}} S \right) = 50 \left( 1 + \frac{1 \times 5}{2.5 \times 1} \right) = 150 \text{tonne/ hour} \]  

(7)

2) Determine specific gravity of intake slurry:

\[ \gamma_c = \frac{\gamma_{s,ph,ph} \gamma_w}{1 + S} = \frac{2.5 \times 1/5 + 1}{1 + 1/5} = 1.25 \text{ tonne } / \text{m}^3 \]  

(8)

3) Determine \( \varepsilon \):

\[ \varepsilon = \frac{\gamma_{s,ph}}{\gamma_w} = \frac{\gamma_c}{\gamma_w} = 1.25 \]  

(9)

4) The unit value of \( q_{op} \) and \( m_{op} \) determined graphically (figure.3):

\( Q_{op} = 1.1 \) and \( m_{op} = 4.5 \)
5) Determine the amount of working fluid:
\[ Q_1 = q_{op} \times Q_c = 1.1 \times 150 = 165 \text{ tonne/hour} \]

6) Determine the pressure of the working fluid in front of the nozzle:
\[ P_1 = \varepsilon \times P_{s, ph, t} \times m_{op} = 1.25 \times 0.1 \times 4.5 = 0.56 \text{ MPa} \]

7) Determine the cross-sectional area at the outlet of the nozzle and its diameter:
\[ f_n = \frac{Q_c}{\sqrt[2]{g P_{s, ph, t} m_{op} \gamma_c}} = \frac{1.1 \times 150 \times 1000}{3600 \sqrt[2]{2 \times 9.81 \times 10000 \times 4.5 \times 1250}} = 0.00138 m^2 = 13.8 \text{sm}^2 \]
\[ d_n = \frac{13.8}{0.785} = 42 \text{mm} \]

8) Determine the cross-sectional area of the displacement chamber and its diameter:
\[ f_k = m_{op} f_n = 4.6 \times 13.8 = 62.1 \text{sm}^2 \]
\[ d_k = \frac{62.1}{0.785} = 8.89 \text{sm} = 88.9 \text{mm} \]

9) The length of the mixing chamber is:
\[ l_k = 6 \times d_k = 6 \times 88.9 = 533.4 \text{mm} \]

10) Determine the liquid discharge supplied by the hydraulic elevator:
\[ Q_{mix} = Q_1 + Q_0 = (1 + q) Q_c = (1 + 1.1) \times 150 = 315 \text{ tonne/hour} \]

11) The diameter of the pressure pipe is:
\[ d_p = \frac{315}{0.785 \times 4 \times 3600} = 0.167 = 167 \text{mm} \]

12) Determine the length of the diffuser with an expansion angle 10°:
\[ l_d = \frac{d_k d_k \cot \alpha}{2} = \frac{445}{2} = 445 \text{mm} \]

Figure 3. Graphic dependence for determining optimal values of \( q_{op} \) and \( m_{op} \).
13) Determine the distance of the nozzle from the entrance to the mixing chamber:

\[ z = 2d_k = 88.9 \times 2 = 177.8\text{mm} \]

4. Conclusion

1. Analysis of the operation of the Tupalong hydroelectric complex showed that during its operation, a significant degree of siltation occurred in the reservoir bowl, and in particular the inlet part of the water body of the inlet head of the water outlet.

2. The average consumption of suspended sediment of the Tupalong river in the village Zarchob is 15.6 kg/sec., which corresponds to runoff of 491 thousand tons. On average, 224 tons of soil are washed off from 1 km² of the catchment (excluding dissolved substances and sediment load). The average turbidity of water in the village Zarchob is 0.305 kg/m³.

3. The average particle size distribution of suspended sediment in the Tupalong River is distributed as follows as a percentage of the total mass: particle diameter > 0.2 mm - 10.8-14.4 %%; particle diameter 0.2 - 0.05 mm - 23.2 - 27.0 %%; particle diameter 0.05 - 0.01 mm - 20.3 - 30.2 %%; particle diameter <0.0132.2 -41.8 %%.

4. The characteristic design of the location of the facilities at the research object contributed to the fact that the inlet head of the first-stage stage water outlet of the Tupalong reservoir was forced to continuously work under different operating conditions by this reservoir. This circumstance contributed to the most intensive sediment deposition and advancement to the water area of the inlet head of the water outlet structure.

5. For the cleaning of siltation and sediment in the water of the inlet head of the first tier of the Tupalong reservoir as an express cleaning method, a hydraulic installation using hydraulic elevators is proposed.

6. Under laboratory conditions, it is planned to simulate the process of cleaning the deposited sediment in the water area of the inlet head of the first-stage water outlet of the Tupalong reservoir;

7. According to the method proposed in the literature (the method of calculating the hydraulic elevator according to S.M.Shtin, the main standard sizes of parts and working bodies of the hydraulic elevator for cleaning deposited sediments in the upper pool of the Tupalong hydroelectric complex are determined.

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