Distribution of turbidity in flow constrained by transverse dam

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Abstract. Construction of control structures in rivers allows to manage channel flow in required direction and artificially change its natural condition providing rational interaction of flow and channel. Redistribution of both liquid and solid flow occur under influence of control structures. The main goal of the given work is to set the distribution pattern of turbidity in flow constrained by transverse blind dam. For the first time the task is studied with the use of field research data from dam №30 in Amudarya river. The location of section and verticals in choosing turbidity samples, the sections are set based on the hydraulic structure of deformed flow. Flow division scheme has been proposed for hydraulically homogeneous zones of weakly disturbed core, intensive turbulent mixing and backflow, as it is accepted in the theory of turbulent flow with mixture spreading in a confined space. For the verticals the samples were taken in two depth points 0.2H and 0.8H, and areas with shallow depth – at 0.6H. Turbidity distribution by depth in weakly disturbed core has the shape of a “boot” and $\mu_{0.8H} \text{ is } 2-3 \text{ times higher than } \mu_{0.2H}$. The rest are close to logarithmic. The maximal turbidity at 0.8H is 3.6 kg/m$^3$. Turbidity distribution in layout in the zone of intensive turbulent mixing is affine and comply with Shlihting-Abramović’s theoretical relationship for starting point. The obtained results can be used in future to forecast interdam area sedimentation and new bank line borders.

1. Introduction

As the result of erosion processes in river basin and river channels solid flow is formed [1,2,3,4], which consists of suspended and bedload sediment. Studying the formation of suspended sediment distribution, as well as forecasting sedimentation of water reservoirs, river floodplains, vortex bank zones are considered to be a topical issue [5,6,7,8]. In the process of channel and flow interaction scouring takes place in one area and sedimentation takes place in other until the channel and flow don’t reach balance. The change of liquid flow result in channel reformation. Control structures allow to manage channel processes, which take place in river channels [9]. Namely with this goal and for the first time in world practice bilateral control of channel was conducted in Amudarya river at the length of 185 km downstream from Tuyamuyun hydrosystem with the use of traverse transverse dams. Design methods for velocity fields, distances between dams, local scouring depth, dam top elevation and their stability were developed [10,11,12,13,14].

Flow obstruction by transverse dams result not only in deformation of velocity field and levels, but also redistribution of flow turbidity both in plane and by depth. Knowing these changes, we can correctly forecast the sedimentation of interdam area as well as the location of new bank line of the river [15,16,17].
2. Method
Field research has been conducted in transverse dam (spur) №30 in Amudarya river. It was chosen with the condition that in the given Turtkul section the main load in deflecting the flow from protected bank has taken place in this region (Fig.1). Dam design length was 120 m, width at the top – 10 m, base width – 18 m, height was 3 m, the distance between dams was 290 m, it was built in 1989, the dam body is built of fine sand by flushing method, and the head section is fixed with rockfill with volume of 2094 м³. Effective length at the time of research (4.09.2019) was 52 m.

![Figure 1. The location of sections and verticals at researched section of the dam №30 (Amudarya river)](image)

The important characteristics of suspended sediment is flow turbidity, which is the amount of suspended sediment per unit volume. The method for determining the turbidity, described in the literature [2,3,4] is given for conditions of hydrometric sections, stations with relatively stable cross section and without separation flow. Our research was held for conditions of channels constrained by blind transverse dams. The presence of transverse dams lead to the change of velocity distribution, water level, transverse and longitudinal slope of water surface, as well as the sedimentation regime in controlled part of the river. Formation of upper and lower vortex zone, contraction and spreading zone, intensive turbulent mixing and back flow zones can be observed. [18].

The sections for sampling were set in places, where natural flow condition is kept, II-II, in contracted section O-O, in compressed section C-C, in sections X-X and B-B within lower vortex zone. Setting the sections, turbulent mixing zone borders and verticals are accomplished with the use of levelling instrument Vega L24.

Verticals were set in the amount of no less than three in one section, also three verticals were set in the zone of intensive turbulent mixing in order to obtain reliable turbidity distribution plot, one vertical was set in the backflow zone.

Samples by depths were taken in two points, that is 0.2H and 0.8H depths, and at 0.6H depth in shallow depths. The samples were poured into clean plastic bottles with section and vertical number marks on them.

The obtained samples were passed through filter paper and weighed on electronic weighs, then the filter paper with sediment was installed in a thermostat at temperature of 180°. After certain amount of time the filter paper with sediment was weighed and the procedure was repeated until the latest results stayed permanent with no change. Then the mass of sediment $G_H$ was determined without filter paper and the flow turbidity was determined with the following expression
\[ \mu = \frac{G_H}{A} \cdot 10^6 \text{ g/m}^3 \]  
\[ \text{where } \mu - \text{ flow turbidity, g/m}^3; \ G_H - \text{ mass of sediment in water sample, g; } A - \text{ sample volume, cm}^3, \ 10^6 - \text{ conversion coefficient from cm}^3 \text{ to m}^3. \]

Mean turbidity for vertical was determined for two-point measurement method

\[ \mu_v = 0.5(\mu_{0.2H} + \mu_{0.8H}) \]  
for one-point measurement method

\[ \mu_v = \mu_{0.6H} \]

From the turbidity values on verticals turbidity distribution plots along section width were built.

3. Results

Field research results are given in Table 1 and in Figures 2, 3 and 4.

**Table 1.** The results for turbidity distribution study in flow constrained by transverse dam №30 (Amudarya river).

| Sections | Verticals | Location of verticals with respect to left bank, m | Water depths, m | Sampling depth, m | Weight of sediment without filter paper, GH, g | Turbidity, \( \mu \text{ kg/m}^3 \) | Mean turbidity for vertical, \( \mu_v \text{ kg/m}^3 \) |
|----------|-----------|---------------------------------------------------|-----------------|------------------|-----------------------------------------------|-----------------|-----------------------------------------------|
| II-II    | I1        | 67                                                | 2.4             | 0.48             | 1.92                                          | 0.78            | 3.6                                           | 3.6              | 2.19                                         |
|          | I2        | 110                                               | 3.8             | 0.76             | 3.04                                          | 1.84            | 1.15                                          | 1.15             | 1.495                                        |
| O-O      | O1        | 81                                                | 2.4             | 0.48             | 1.92                                          | 0.39            | 2.28                                          | 2.28             | 1.335                                        |
|          | O2        | 132                                               | 6.8             | 1.36             | 5.44                                          | 1.61            | 1.34                                          | 1.34             | 1.475                                        |
| C-C      | C1        | 40                                                | 1.5             | 0.3              | 1.2                                           | 1.28            | 2.17                                          | 2.17             | 1.725                                        |
|          | C2        | 101                                               | 2               | 0.4              | 1.6                                           | 1.3             | 1.74                                          | 1.74             | 1.52                                         |
|          | C3        | 117                                               | 3.7             | 0.74             | 2.96                                          | 1.21            | 1.81                                          | 1.81             | 1.51                                         |
|          | C4        | 127                                               | 5.5             | 4.4              | 0.84                                          | 1.76            | 0.84                                          | 0.84             | 1.3                                          |
|          | C5        | 140                                               | 6               | 1.2              | 4.8                                           | 0.77            | 1.09                                          | 1.09             | 0.93                                         |
|          | C6        | 213                                               | 2.9             | 0.58             | 2.32                                          | 0.41            | 0.75                                          | 0.75             | 0.58                                         |
| X-X      | X1        | 30                                                | 2.5             | 0.5              | 2                                             | 0.99            | 3.15                                          | 3.15             | 2.07                                         |
|          | X2        | 60                                                | 2.7             | 0.54             | 2.16                                          | 0.93            | 2.91                                          | 2.91             | 1.92                                         |
|          | X3        | 75                                                | 1.8             | 0.36             | 1.44                                          | 0.85            | 1.54                                          | 1.54             | 1.195                                        |
|          | X4        | 112                                               | 3.6             | 0.72             | 2.88                                          | 2.02            | 1.33                                          | 1.33             | 1.675                                        |
|          | X5        | 150                                               | 5.5             | 1.1              | 4.4                                           | 0.71            | 2.12                                          | 2.12             | 1.415                                        |
|          | X6        | 170                                               | 0.5             | 0.3              | 1.23                                          |                 | 1.23                                          |                 | 1.23                                         |
|          | X7        | 213                                               | 2               | 0.4              | 1.6                                           | 0.61            | 0.78                                          | 0.78             | 0.695                                        |
| B-B      | B1        | 20                                                | 1.2             | 0.24             | 0.96                                          | 0.73            | 2                                             | 2                | 1.365                                        |
|          | B2        | 70                                                | 2.6             | 0.52             | 2.08                                          | 0.88            | 1.84                                          | 1.84             | 1.36                                         |
|          | B3        | 120                                               | 5               | 1                | 4                                             | 0.79            | 1.51                                          | 1.51             | 1.18                                         |
|          | B4        | 150                                               | 3.5             | 0.7              | 2.8                                           | 0.6             | 1.04                                          | 1.04             | 0.82                                         |
|          | B5        | 190                                               | 0.9             | 0.54             | 0.57                                          |                 | 0.57                                          |                 | 0.57                                         |
|          | B6        | 216                                               | 1.5             | 0.3              | 1.2                                           | 0.33            | 0.45                                          | 0.45             | 0.39                                         |
As seen from Table 1 and Figures 2 and 3, the value for turbidity increases by depth and complies with logarithmic law of distribution. For all that the maximal change of value for turbidity on headrace reaches on vertical Π1 at 0.8H depth and is equal to 3.6 kg/m³. On verticals Π2 and O2 certain levelling and turbidity decrease can be observed, that is 1.84 for 0.2H, and 1.15 for 0.8H, 1.61 for 0.2H and 1.34 for 0.8H. This explains, that the presence of dam assists in redistribution of turbidity by flow depth in the zone of its influence. In the zone of weakly disturbed core between x-axes and beam 01 – y1, the pattern of turbidity distribution by depth reminds of a “boot” and the values μ0,8H are two, three times are higher than that for μ0,2H. In the zone of turbulent mixing between beams 01 – y1 и 01 – y2 don’t exceed two.

Turbidity distribution pattern by depth in backflow zones on verticals C6, X7, B6, keeping the basic view, the difference between μ0,8H and μ0,2H don’t exceed 1.2 ± 1.5. C6, X7, B6 keeping the general view the difference between μ0,8H and μ0,2H doesn’t exceed 1.2 ± 1.5. It is necessary to consider that the shallow depths on verticals X7 and B6 mean that certain sediment deposition took place in the vortex zone.

Figure 2. Turbidity distribution with flow depth in sections Π-Π, 0-0.
Figure 3. Turbidity distribution with flow depth in sections C-C, X-X, B-B.
It is of a certain interest that turbidity distribution analysis with flow width, i.e. in plane. It is seen in Tables 1 and 2.
Figure 4. Turbidity distribution in plane.
Turbidity distribution in plane for the zone of weakly disturbed core don’t differ much from section to section and ranges from 1.36 to 2.07 kg/m$^3$. Turbidity distribution pattern in the theory of turbulent flow, sediment concentration in the zone of turbulent mixing is of a great interest. The studies [19, 20] has shown that turbidity distribution in this zone comply with Shlihting-Abramovich relationship

$$\frac{\mu - \mu}{\mu_0 - \mu} = 1 - \eta$$

(4)

where $\mu, \mu_0, \mu$ - turbidity (sediment concentration) in the core, in backflow and in the zone of turbulent mixing; $\eta = \frac{y_2 - y}{y_2 - y_1}$ - relative ordinate of the point, where $\mu$ is determined; $y_1, y_2, y$ - ordinates for beams $0^1 - y_1; 0^1 - y_2; 0^1 - y$. Field data from Table 1 were input into chart (Figure 4.), from which it can be noted, that turbidity distribution in intensive turbulent mixing zone comply with the theoretical relationship of Shlihting-Abramovich, proposed for head part of the flow (Figure 5). In our case the degree of flow contraction by dam №30 equals 0.24, which means that flow spreading takes place within the specified region. Maximum deviation from theoretical values is 16.6%.

Figure 5. Distribution of turbidity in the zone of intensive turbulent mixing.
4. Discussion
Blind transverse dams for channel control and bank protection are the most spread type of control structures. Their cost effectiveness compared to longitudinal dams are generally recognized, due to that they protect the region of 2-3 times the dam length and the use of local construction materials for its structure.

For the first time the scheme of bilateral channel control for Amudarya river length of 185 km from Tuyamuyun to Kipchak has been accomplished. The scheme provides the construction of transverse dams. Due to the high turbidity of Amudarya river ($\mu = 12$ kg/m$^3$) intensive sedimentation takes place in the vortex zone of interdam area. We are the first to conduct field measurements for flow turbidity distribution in dam influence zone of 30 m in Turtkul region of the river. Turbidity sampling was accomplished from hydrometric boat with the use of bathometer bottle. Sample analysis was done in the laboratory “Construction materials” of Tashkent institute of irrigation and agricultural mechanization engineers. For the analysis flow division scheme into hydraulically homogeneous zones by velocity and turbidity was used: weakly disturbed core, intensive turbulent mixing zone and backflow zone.

Turbidity distribution patterns were determined by verticals and in plane along river width. It was determined that turbidity in the zone of weakly disturbed core in plane stay even to some degree, and in the zone of turbulent mixing it complies with Shlihting-Abramovich relationship on the head region and it is affine.

5. Conclusions
1. For the first time field research was conducted in determining patterns for turbidity distribution for flow deformed by blind transverse dam.
2. As opposed to existing methods the sections for study were determined depending on the structure of deformed flow; in back-up sections in headrace, in contraction zone, in compressed zone, intermediate sections and at the end of vortex zone. The number of verticals were set to be no less than three in the zone of intensive turbulent mixing.
3. In the zone of weakly disturbed core the turbidity distribution plot by depth has the shape of a “boot” and the turbidity at 0.8H depth is two to three times lower than that for the depth of 0.2H.
4. Turbidity distribution in plane, constructed by the mean turbidity in verticals in the zone of weakly disturbed core is identical to the name “core”.
5. The affinity of turbidity distribution has been determined for the zone of intensive turbulent mixing and it complies with the theoretical relationship of Shlihting-Abramovich for the head region of flow.
6. Research results allow to forecast sedimentation of interdam area.

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