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PROBLEMS OF HYDRAULIC CALCULATION OF EARTHEN CHANNELS

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Abstract. *The main task of the design of earthen channels is to calculate the dimensions of the stable channel shape in which irreversible deformation of the channel cross-section does not occur. This article provides information on calculating the hydraulic parameters of a stable channel shape in the design of earthen channels in which channel deformation does not occur.*

In this case, the need to adopt dynamic stable channel parameters that can work in harmony with nature through the method of checking the dynamic stability of the channel with the help of hydraulic modeling programs is based on modeling using HEC-RAS software and field-experience data.

Based on the research results, a new approach is required in the hydraulic calculation for the design of the earthen canals, taking into account the changing nature of the flow and discharge. Taking into account the natural increase of the bottom slope of the deformed channel bed due to sediment deposition, it is suggested to strengthen the side embankments of the channel and choose the flow slope that ensures the balance of the sediment balance.

The essence of the proposed method consists in adopting dynamic stable channel parameters that are in harmony with nature and do not require continuous cleaning and repair works in the calculation of earthen channels. For this, it is necessary to model the sediment transport with the help of hydraulic modeling programs of the earthen channels.

Keywords: *dynamic stable channel, hydraulic calculation of earthen channels, suspended sediment concentration, channel deformation, hydraulic calculation methods*

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ВОПРОСЫ ГИДРАВЛИЧЕСКОГО РАСЧЕТА ЗЕМЛЯНЫХ КАНАЛОВ

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Аннотация. *Основной задачей проектирования земляных каналов является расчет размеров устойчивой формы канала, при которой не происходит необратимой деформации поперечного сечения канала. В данной статье приведены сведения по расчету гидравлических параметров устойчивой формы русла при проектировании земляных каналов, в которых не возникает русловых деформаций.*

В этом случае необходимость принятия динамически устойчивых параметров русла, способных работать в гармонии с природой, посредством метода проверки динамической устойчивости русла с помощью программ гидравлического моделирования основана на моделировании с использованием программного обеспечения HEC-RAS и данных натурного эксперимента.

По результатам исследований требуется новый подход при гидравлическом расчете при проектировании земляных каналов с учетом изменяющегося характера стока и расхода. Учитывая естественное увеличение уклона дна деформированного русла канала за счет отложения наносов, предлагается укрепить боковые насыпи канала и выбрать уклон дно канала, обеспечивающий сбалансированность баланса наносов.

Суть предлагаемого метода заключается в принятии при расчете земляных каналов динамических устойчивых параметров русла, гармонирующих с природой и не требующих постоянных работ по очистке и ремонту. Для этого необходимо смоделировать транспорт наносов с помощью программ гидравлического моделирования земляных каналов.

Ключевые слова: *динамический устойчивый канал, гидравлический расчет земляных каналов, концентрация взвешенных наносов, деформация русла, методы гидравлического расчета.*

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GRUNT O‘ZANLI KANALLARNI GIDRAVLIK HISOBLASh MASALALARI

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Annotatsiya. *Grunt o‘zanli kanallarni loyihalashning asosiy vazifasi bu ortga qaytmas o‘zan deformatsiyalanishi sodir bo‘lmaydigan mustahkam kanal shaklining o‘lchamlarini hisoblashdan iborat. Maqolada grunt o‘zanli kanallarni loyihalash uchun gidravlik hisoblashda o‘zan deformatsiyalanishi sodir bo‘lmaydigan mustahkam kanal parametrlarini hisoblash masalalari to‘g‘risida ma’lumotlar berilgan.*

Bunda gidravlik modellash dasturlari yordamida kanalni dinamik mustahkamlikka tekshirish usuli orqali tabiat bilan hamohang ravishda ishlay oladigan dinamik mustahkam kanal parametrlarini qabul qilish zarurligi HEC-RAS dasturi yordamida modellashtirilgan va dala-tajriba ma’lumotlari bilan asoslanadi.

Tadqiqot natijalariga ko‘ra, grunt o‘zanli kanallarni loyihalash uchun gidravlik hisoblashda oqim va oqiziqning o‘zgaruvchan xarakterini hisobga olgan holda yangicha yondashuv talab qilinadi. Bunda loyqa bosishi tufayli deformatsiyalangan kanal o‘zani tub nishabligining tabiiy ravishda oshishini hisobga olgan holda kanal yon dambalarini mustahkamlash va oqiziq balansining muvozanatini ta’minlaydigan oqim nishabligini tanlash taklif qilinadi.

Taklif etilayotgan usulning mohiyati grunt o‘zanli kanallarni hisoblashda tabiat bilan hamohang va uzluksiz tozalash ta’mirlash ishlarini talab qilmaydigan dinamik mustahkam kanal parametrlarini qabul qilishdan iborat. Buning uchun grunt o‘zanli kanallarni gidravlik modellash dasturlari yordamida oqiziq transportini modellash talab etiladi.

Kalit so‘zlar: *dinamik mustahkam kanal, grunt o‘zanli kanallarni gidravlik hisoblash, muallaq oqiziq konsentratsiyasi, o‘zan deformatsiyasi, gidravlik hisoblash usullari.*

Introduction

Earthen channels are artificial engineering structures that are considered to be an integrated system where stream and channel morphometric elements are naturally connected. One of the most important and complex issues in the design of channels in natural channel beds in irrigation systems is the issue of correctly considering the interaction of turbulent flow dynamics with the channel bed.

The main task of the design of earthen channels is to calculate the dimensions of the stable channel shape in which irreversible deformation of the channel cross-section does not occur. The deformation of the channel leads to a loss of flow capacity of the channel cross-section [1-3].

Since the stability of the channel cross-section is the main factor for the reliable use of the channel, it is necessary to follow the following requirements in the design of channels: the channel should not be eroded and deposited, the overall satbility of the cross section should be ensured, the channel bed should have enough flow capaciity, and the minimum loss to filtration should be achieved from the channel bed.

The design of canals that meet these requirements and the reconstruction of existing irrigation canals are now considered as the main factor in the modernization of irrigation and reclamation systems in many developed countries [4].

Chow, Raudkivi, Simons and Sentürk, Wallingford and others noted the following four methods of hydraulic calculation for the design of stable channels:

- regime method;
- tractive force method;
- method of permissible velocities;
- rational method [5, 6].

Methods and materials

The method of permissible velocities is used in our republic for the design of channels.

When designing channels according to the method of permissible velocities, the average velocity in the channel should be as follows [1]:

$$\vartheta_l < \vartheta < \vartheta_{yu} , \quad (1)$$

where:

ϑ_l – the minimum permissible velocity in which sediment deposition does not occur, m/s;

ϑ_{yu} – the maximum permissible velocity in which channel bed erosion does not occur, m/s;

According to the norms and rules of urban planning (SHNQ 2.06.03-12), it is recommended to determine the (minimum) permissible velocities without deposition is as follows:

taking into account the effect of suspended sediments in the flow:

$$\vartheta_л = A * Q^{0,2} , \quad (2)$$

A – is an empirical coefficient and is determined depending on the fall velocity.

$W < 1,5\ mm/s$ when $A = 0,33$;

$W = 1,5 \div 3,5\ mm/s$ when $A = 0,44$;

$W > 3,5\ mm/s$ when $A = 0,55$.

However, compared to the tractive force method, the permissible velocities method cannot accurately represent the physical processes between the bottom material and the flow. Therefore, according to Ankum (Ankum), the method of permissible speeds should no longer be used [7].

Currently, irrigation canals are calculated mainly for the steady flow of water. Also, it is assumed that there is a state of balance in which there is no deposition and erosion, and the water entering the channel and the flow are completely transferred. Nevertheless, a steady uniform flow is rare in nature. Because the sediment transport is highly dependent on the flow condition, the sediment capacity of the channel also changes with flow condition [4].

At present, channel bed of canals such as Mirishkor and Karshi main canals, which receive water from the Amudarya in the southern part of our republic, have become deformed due to the sediment deposition and their flow capacity has decreased [1-3, 8].

Figure 1. General view of Mirishkor canal at PK 180 station

Our research has shown that the flow velocities in these large irrigation canals are within the permissible range only in the months when maximum flow discharge is observed. We can observe that the flow velocity decreases from the design values due to the increase of the wetted perimeter and correspondingly the amount of hydraulic resistance to the flow, and the sediment transport capacity of the flow is insufficient [1-3].

So, what should be done to prevent sedimentation in these channels, why are sediment deposition observed in channels built according to existing standards, what should be paid attention to in canal reconstruction projects so that sedimentation does not happen again?

In the fight against the sedimentation processes, work is carried out in the following main directions:

1. Control of sediment flow in tributaries at the beginning of the river from which the canal receives water;
2. Construction of sediment traps at the head of irrigation canals and timely cleaning of the sediments trapped there;
3. When designing the parameters of the irrigation channel, ensure that it has the capacity to transport suspended sediments.

In the case of the Mirishkor and Karshi main canals receiving water from the Amudarya, it is impossible or too expensive to carry out work in the first and second directions, so it is most appropriate to choose third direction, i.e. adopting the parameters of the dynamic stable channel.

A dynamic stable channel means a channel in which deformation of the channel bed (silting or washing) can be observed during the year, but in general, at the end of the year, due to the balance of the sediment balance, the channel cross-section maintains sufficient flow capacity.

To calculate dynamic stable channels, it is necessary to take into account complex processes related to fluid transport in rivers and channels. Lane's well-known "Sediment -Water Balance law" expresses the interrelationship between bed morphometry, sediment and flow parameters in earthen canals with the following formula.

$$Q_s \cdot d_{50} \propto Q \cdot i \,,$$

where Q_s - sediment discharge, d_{50} - median particle diameter, Q - flow discharge, i - bed slope.

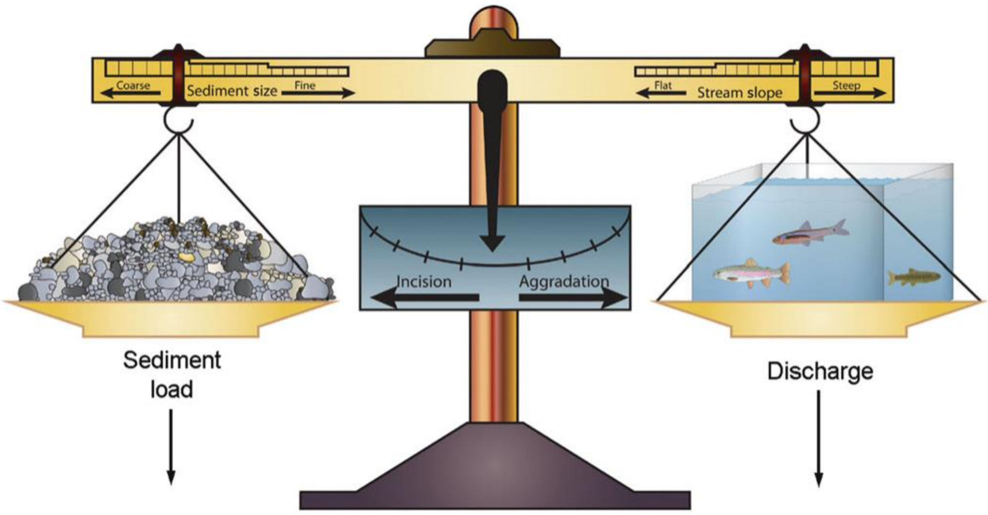

Figure 2. Diagram illustrating Lane's "Sediment -Water Balance Law" (Sourced from Hohensinner 2018)

As can be seen from the diagram, according to Lane, with an increase in the flow discharge, the erosion process of larger size particles at the bottom of the channel begins, and the channel bed slope decreases along the length of the channel. Or, on the contrary, if the sediment discaherge of large particles in the stream is greater than the sediment transport capacity of the stream, an increase in the slope of the channel bottom is observed due to the settling of larger size particles suspended particles at the beginning of the channel [9].

Results

When the suspended sediment concentration is measured in several sections of the Mirishkor channel along the channel length, it is observed that the concentration of suspended sediments in the flow decreases along the channel length and in proportion to the decrease in flow discharge, Fig. 3.

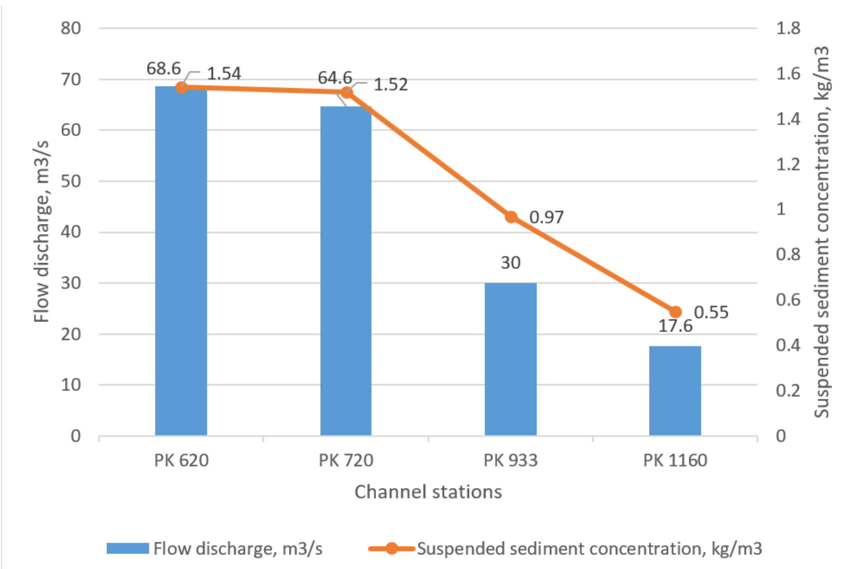

Figure 3. The graph of the dependence of the amount of sediment concentration on the flow discharge

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By selecting a 950-meter long channel section in the Mirishkor channel from PK9+50 to PK19, and modeling the sediment transport using the HEC-RAS program, we can see the increase in the slope of the channel bed over time, Fig. 4.

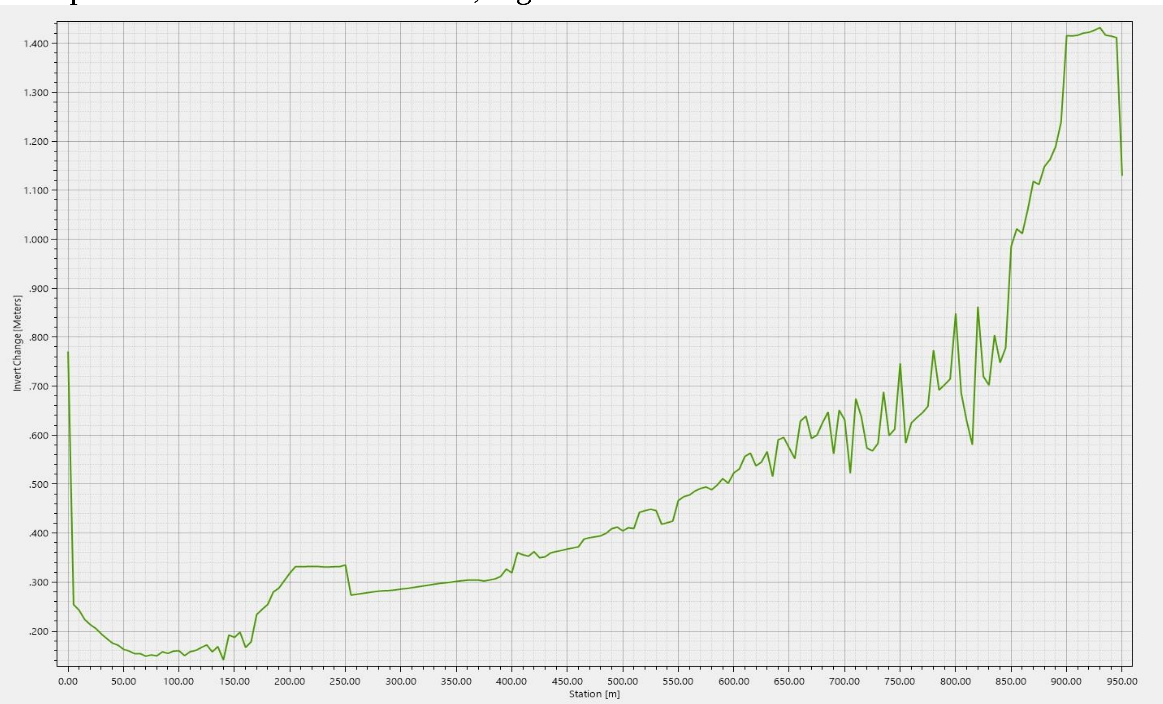

Figure 4. Results of modeling the evolutionary change of the channel bed level in the Mirishkor channel from PK9+50 to PK19 using HEC-RAS software (flow direction from right to left)

If we compare the flow hydraulic parameters measured in 2016-2019 in PK 245 station of the Mirishkor canal with the design parameters of the canal in Table 1, we can see that the actual average flow velocities even at small flow discharges are greater than the average design flow velocity for normal flow discharge. We can see that one of the reasons for this is the reduction of the flow cross-sectional area and the increase of the flow slope due to the channel bed deformation [1].

Table 1.

Design parameters of the canal section at PK 245+00 station

№	Flow discharge, Q, m³/s	Channel bed width, b, m	Width across the water surface, B, m	Maximum flow depth h, m	Channel bed slope, J	Cross-sectional area ω, m	Average flow velocity, V, m/s
1	139.8	21.5	67.0	5.7	0.00003	241.03	0.58

Table 2.

Actual parameters of the channel section measured at PK 245+00 station at different flow discharges

№	Flow discharge, Q, m³/s	Width across the water surface, B, m	Maximum flow depth h, m	Cross-sectional area ω, m	Average flow velocity, V, m/s	Date of measure
1	54.403	42.4	3.05	86.965	0.626	07.03.2016

2	79.873	47.4	3.32	106.49	0.75	16.07.2016
3	84.683	48.7	3.52	104.39	0.811	14.04.2017
4	55.003	44.24	3.28	97.03	0.567	10.07.2017
5	51.95	41.42	3.31	92.74	0.56	02.04.2018
6	53.179	41.12	3.24	90.86	0.585	16.08.2019

Taking into account M.A. Velikanov's famous phrase "The stream controls the channel, and the channel controls the stream", it can be concluded that the stream "controls" the channel geometry during long-term operation, that is, cross-sectional area of the flow decreased and its flow velocity increased slightly. Through this, it can be concluded that the flow is moving towards the most favorable hydraulic section and increasing its energy slope [10].

According to the recommendations of Y.A.Ibadzada, one of the ways to increase the flow capacity of irrigation canals is to increase the energy slope in the canal in a suitable condition [11].

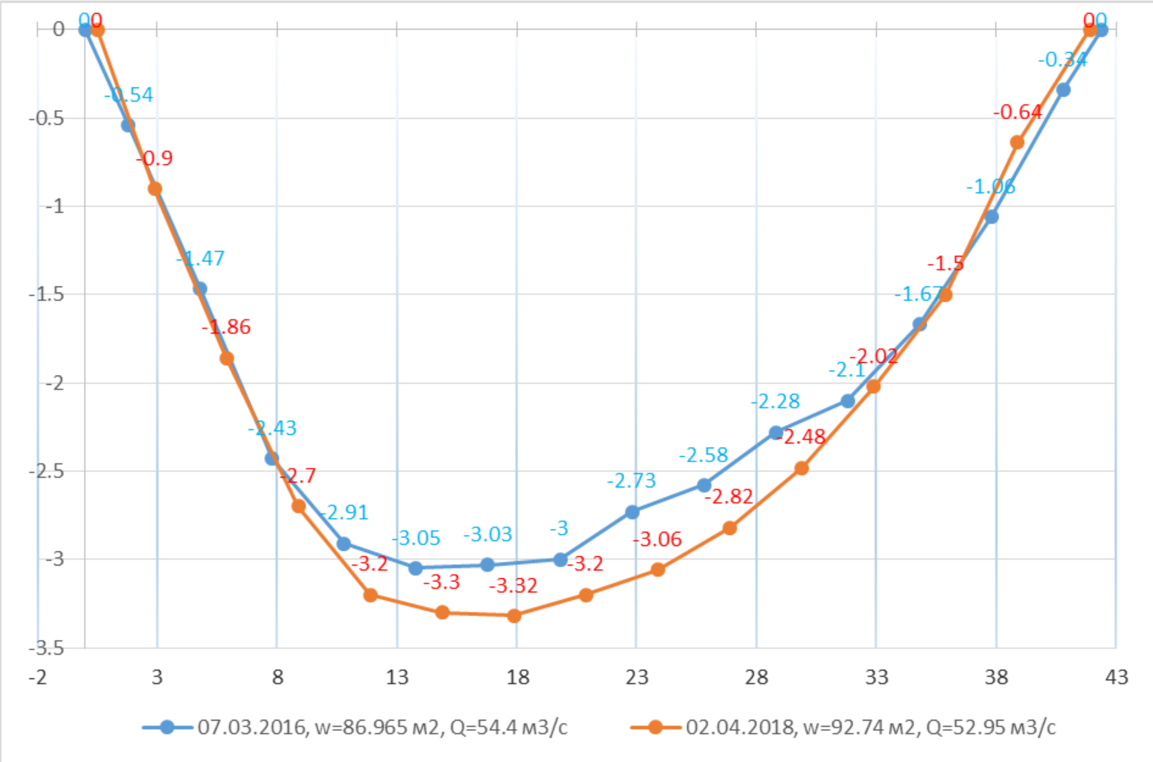

Figure 3. Results of measurements conducted in 2016 and 2018 in Mirishkor canal PK245 station

It should be noted that if the Karshi main canal and Mirishkor canals are mechanically cleared of deposited sediments and brought to their design parameters, the condition will be created for the beginning of a more intensive silting process due to the reduction of the energy slope in these canals.

Taking this into account, when drawing up a project for the reconstruction of these main channels, it is possible to increase the bed slope of the channel sections, by considering the increase of the channel embankment with the sediment mass removed from the channel bed, and by adapting the weir structures to this raised level. This, in turn, leads to an increase in the flow rate in these channel sections and a slowdown in the process of sediment deposition.

Conclusion

According to the ancient philosopher Laozi, “Dao or the Way acts through non-action”, that is, human-built structures should be built on the basis of naturalness, not on the basis of any attempts to stop the rhythm of nature [12].

Therefore, we should change our approach for designing canals. That is, the dimensions of the channel must be suitable with changing pattern of sediment and flow discharge. For this, the main task in the reconstruction of the Mirishkor and Karshi main canals is not to return the canal to the design values, but to increase the hydraulic slope of the canal embankment and the hydraulic slope in the canal according to the recommendations of Y.A. Ibadzada by the method of checking the canal parameters for dynamic stability. Because the earthen canals themselves are made of natural material and the water flow is also a part of nature, best way to design an earthen canal is calculating the parameters of dynamic stable canal that keeps its shape naturally without requirements of any repair.

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