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Improvement of vehicle park composition used in the construction of concrete lined canals

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Abstract

This study comprehensively evaluates previous research on the hydraulic performance, structural strength, and construction technologies of concrete-lined irrigation canals. While the literature focuses on fundamental studies related to open channel hydraulics, sediment transport, and channel geometry optimization, it also highlights the growing importance of issues such as frost damage, temperature-stress effects, quality control, and hydraulic efficiency in concrete-lined canals. Concrete linings are widely preferred in modern irrigation systems due to their ability to reduce water losses, increase channel strength, and lower maintenance costs. However, the study reveals that the structure and mechanization level of the machinery used in the construction of concrete-lined irrigation canals have a decisive impact on the quality of the application. The use of specialized canal excavation, concrete paving, and surface leveling machines reduces labor requirements, increases construction speed, and improves quality standards. The study also notes that general-purpose machinery is predominantly used in current applications, leading to efficiency losses. In conclusion, the use of modern and highly efficient machinery in irrigation canals is considered a strategic necessity for sustainable water management, economic efficiency, and agricultural development.

Keywords: irrigation canal, concrete lining, excavator with one-wheel, concrete lining, technological process.
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1. Introduction

Irrigation canals are one of the most important areas of study in hydraulic engineering in terms of the sustainability of agricultural production and the efficient use of water resources. The basic principles of open channel flow theory were first discussed in detail in classical studies developed by Ven Te Chow; canal hydraulics, flow regimes and water transmission mechanisms were comprehensively examined [1]. Later studies carried out by Walter Hans Graf focused on sediment transport and canal stability; they made significant contributions to the issues of bed erosion, sediment movement and canal durability, especially in open channels [2]. For the long-term performance of irrigation canals, not only hydraulic behavior but also the optimization of canal geometry and soil properties are important. In this context, Mikhalev and Chirikina [3] investigated optimum design solutions for earth canals and developed methods for the economic and hydraulic evaluation of canal cross-sections. Similarly, Mikhalev and Obodova [4] conducted analyses on the optimum bed geometry and operating conditions of main irrigation canals and presented engineering approaches to increase canal efficiency. Over time, water losses, leaks, base deformations, and maintenance costs in irrigation networks have further increased the importance of concrete-lined canal systems. Especially in modern irrigation infrastructures, concrete-lined canals are widely preferred because they increase water transmission efficiency, reduce leaks, and lower maintenance requirements. However, the structure and efficiency of the machinery used in the construction of concrete-lined irrigation canals have become a critical factor in terms of application quality and economic sustainability. Specialized machines used in canal excavation, concrete paving, surface leveling, compaction, and drainage applications reduce labor requirements, shorten construction time, and improve application standards.

In this context, the development of canal lining technologies and the increase in the level of mechanization are considered one of the basic requirements of modern irrigation systems. Studies by Kumar and Deshpande [5] revealed that deteriorations in traditional canal linings negatively affect irrigation efficiency, emphasizing the importance of modern concrete lining systems and efficient machine use. Jadhav et al. [6] showed that canal lining significantly improves water transmission efficiency and makes important contributions to water conservation, especially in large irrigation areas. Li et al. [7] numerically investigated the damage mechanisms caused by frost heave in concrete-lined canals using the XFEM method and revealed the critical role of low-temperature effects on lining integrity. In the study conducted by Wang et al. [8], the construction planning and quality control processes of bagged concrete applications in Hetao Irrigation Area were examined; it was stated that the correct equipment selection and work organization directly affect the canal lining quality. Qingfu [9] investigated the main causes of structural damage in irrigation canal linings and emphasized that inadequate construction techniques, low-quality applications, and the use of unsuitable equipment are important risk factors. Li et al. [10] developed statistical analysis and cloud model-based approaches in the quality assessment of large-scale concrete canal linings, revealing the role of mechanized construction processes in quality assurance. Liu et al. [11] investigated the frost heave mechanism in water transmission canals and presented suggestions for optimizing slope protection systems. Li et al. [12] modeled the damage occurring in concrete canal lining plates by considering the temperature-stress-water load interaction and analyzed the effects of environmental factors on structural performance. Wanyama and Bwambale [13] contributed to increasing water transmission efficiency by conducting hydraulic modeling studies to improve flow conditions in irrigation canals. In the study conducted by Fan et al. [14], hydrothermal coupling and frost heave behaviors in trapezoidal concrete-lined canals in cold regions were investigated. When these studies are evaluated together, it is seen that structural strength, quality control, hydraulic efficiency, and appropriate construction technologies are of great importance in concrete-lined irrigation canals. Finally, Gajbhiye et al. [15] has shown that geotextile-reinforced composite concrete linings provide high strength and long service life in sustainable canal structures. When these studies are considered together, the use of modern and highly efficient machinery in the construction of concrete-lined canals in contemporary irrigation infrastructures is deemed a strategic necessity in terms of economic efficiency, sustainable water management, and agricultural development. Furthermore, these studies show that structural strength, quality control, hydraulic efficiency, and appropriate construction technologies are of great importance in concrete-lined irrigation canals.

In recent years, in our country, which is integrated on a global scale, newly constructed or rehabilitated irrigation canals and collector-drainage networks must also meet world standards. For this purpose, machinery that meets world standards and modern requirements is needed during the rehabilitation and construction of irrigation canals and collector-drainage networks. In this context, it is shown that the construction and operation organizations affiliated with Azerbaijan Amelioration and Water Management OJSC are carrying out large-scale work in this direction. However, analyses of the composition of OJSC's current machinery park reveal that these works are carried out using general-purpose construction machinery due to the lack of specialized canal excavation, canal cleaning, concrete paving, or underground drainage laying machines within the organization. Research indicates that specialized concrete paving machines are not currently used for irrigation canals. However, the use of such machines would not only significantly reduce labor requirements and operating costs, but also improve the quality and efficiency of the concrete lining technological process in irrigation canals of varying sizes. Furthermore, the canal bed slope was theoretically analyzed in this study, and the optimum slope is determined.

2. Theoretical development

Currently, the Central Mugan Collector Operation Department is working on the reconstruction of the Kyzylarkh irrigation canal in the Imishli district. Observations made at the construction site show that during operation, this earthen bed channel was overgrown with various vegetation and silted up, because of which its water-permeable capacity decreased. During the reconstruction of the canal, the canal water was blocked, and its bed was compacted and filled with layers of soil brought from outside (from the dams).

For many years of the past century, researchers sought such a cross-section of an earthen channel in which the resultant force acting on each soil particle would be identical at every point of the wetted perimeter. A solution to this problem can be found in studies [1,2]. However, in practice it is almost impossible to implement a structurally uniform cross-section of a channel.

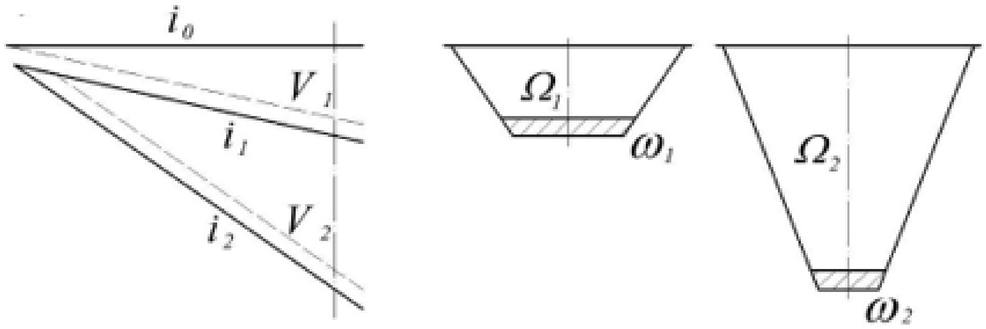

Figure 1. A longitudinal profile of two channels and the corresponding cross-sections of excavation at the end points

Let us turn to the idea expressed in [3,4] and explain its meaning using the diagram (figure 1). In figure 1, a longitudinal profile of two channels and the corresponding cross-sections of excavation at the end points are shown. The following notations are introduced in the figure: i_0 is the slope of the terrain along which the channel route passes; i is− the slope of the channel bed under uniform water flow; $\omega$is the wetted cross-sectional area of flow; Ω is the volume of soil lying above the water level in the channel that must be excavated in order to provide the channel bed with the required slope along its entire course. For greater clarity of the illustration, the terrain slope is taken to be zero. Further, we shall consider terrains where the surface slope satisfies the condition $i_0 \geq 0$, if channel routes bypass sections of land with reverse slopes because of the considerable increase in the volume of earthworks.

With a large channel bed slope i_2, the water flow velocity U_2 $\boldsymbol{U_2}$ is high, while the wetted cross-sectional area $\boldsymbol{\omega_2}$ at the considered section (for a constant discharge) is small, whereas the excavation area $\Omega_2$is large. Conversely, with a small bed slope i_1, the wetted cross-sectional area $\boldsymbol{\omega_1}$ is large, and the excavation area $\Omega_1$is small. From the diagram it follows that the total excavation volume along the entire length of the channel depends on the sum of the areas $\Omega + \omega$, while the channel length itself depends on the bed slope. From this it follows that, under certain conditions, there exists a minimum volume of earthworks V_{min}, which corresponds to the minimum value of the sum of areas $(\Omega + \omega)_{min}$. The corresponding bed slope of the channel can be defined as the optimal slope (figure 2).

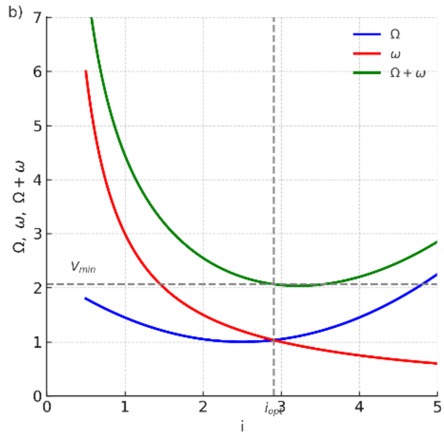

Figure 2. A diagram illustrating the existence of a minimum volume of earthworks at the optimal channel bed slope

Consider a channel with a composite trapezoidal cross-section, where the side slope coefficients within the wetted section are m and above the water surface are m_1 (figure 3). Suppose it is required to deliver a discharge Q from point A to point C, with the channel alignment being rectilinear and the wetted cross-sectional area equal to ω. At point A, the water level in the channel is assumed to coincide with the ground surface. As is known, the channel bed slope equals $tan\alpha$, where α is the angle of inclination of the channel bed relative to the horizontal line. The distance from point A to point C along the ground surface in a straight line is l. In this case, the length of the channel between the two points is equal to the length of the hypotenuse of the triangle: $\sqrt{l^2 + l^2 i^2} = l\sqrt{1 + i^2} \approx 1$, since $i << 1$.

Thus, when determining the earthwork volume, the channel length can, without significant error, be taken as l. The water depth in the channel is denoted as h. Since the water flow in the channel is uniform, the wetted cross-sectional area at point C is equal to ω. The bottom width of the channel is b, while the water surface width is B_1. Considering the slopes of the bed and the ground surface, the excavation depth at point ***C*** becomes z. The channel width at the top (at ground surface level) at its end section is B_2.

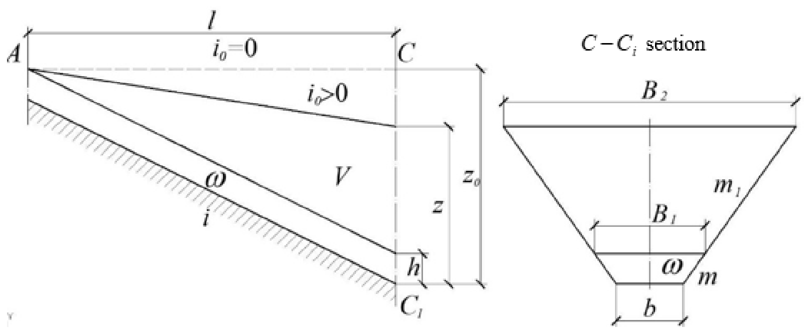

Figure 3. Diagram for calculating the volume of earthworks

The volume of earthworks for constructing a channel of length $l$is determined as the sum of the volumes of its individual geometric elements. As the first element, consider a prism with base area $\boldsymbol{\omega}$ and height equal to the distance l; the excavation volume isωl. Next, consider two pyramids, each having as a base a right triangle with an area of $0.25(z - h)(B_2 - B_1)$. Let us express the excavation depth z at point C through the depth $z_0$at the same point in the case where the ground surface is horizontal (see, figure 3**)**, using the following identity: $z = z_0 - (z_0 - z) = z_0 - li_0$, where $z_0 - z = z_0 - li_0$. In addition, note that $z_0 - h = li_0$. Using these transformations, the volume of soil in the two pyramids, whose bases are the above-mentioned triangles, is determined as: $l^3(i - i_0)^2 m_1/3$. It remains to determine the soil volume in the wedge located in the central part of the channel above the water level: $0.5l^2(i - i_0)B_1$.

Thus, the volume of earthworks required for constructing a channel of length $\boldsymbol{l}$ is determined from the following relation:

$$V = \omega l + l^3(i - i_0)^2 m_1/3 + 0.5l^2(i - i_0)B_1 \quad (1)$$

Let us express equation (1) in a dimensionless form:

$$V/\omega l = 1 + l^2(i - i_0)^2 m_1/3\omega + l(i - i_0)B_1/2\omega \quad (2)$$

For trapezoidal cross-section channels, we have: the wetted cross-sectional area $\omega = h^2(\beta + m)$, and the water surface width at the top of the channel $B_1 = h(\beta + 2m)$ where $\beta = b/hx = i/h, x_0 = li_0/h$ is the relative bottom width of the channel.
Let us denote: $x = i/h, x_0 = li_0/h$ then we obtain

$$V/\omega l = 1 + (x - x_0)(\beta + 2m)/2(\beta + m) + (x - x_0)^2 m_1/3(\beta + m) \quad (3)$$

Let us perform the transformations on the left-hand side of equation (3) using hydraulic formulas:

$$\Omega = Q/U, U = \sqrt{2gR_i/\lambda} \quad (4)$$

where Q is water consumption in the canal and $U$is water flow velocity in a canal; R is the hydraulic radius; λ is the hydraulic friction coefficient; g is the gravitational acceleration. We arrive at the following expression:

$$V/\omega l = \frac{V\sqrt{2gRh/\lambda}}{lQ} = V_r\sqrt{x} \quad (5)$$

where V_r is the reduced (dimensionless) volume of works:

$$V_r = V\sqrt{gRh}\frac{\sqrt{x}}{lQ\sqrt{\lambda l}} \quad (6)$$

The actual volume of works is equal to:

$$V = V_r \omega l\sqrt{x} \quad (7)$$

Let us substitute in (3) according to (7), divide the left and right sides of (7) by $\sqrt{\boldsymbol{x}}$, and obtain:

$$V_r = \sqrt{x}[1 + (x_0^2 m_1)/3(\beta + m) - x_0(\beta + 2m)/2(\beta + m)]$$
$$+\sqrt{x}[(\beta + 2m)/2(\beta + m) - 2x_0 m_1/3(\beta + m)] + x\sqrt{x}m_1/3(\beta + m) \quad (8)$$

It may turn out that the flow velocity of water in a canal of optimal dimensions exceeds the non-eroding velocity for the soil particles forming the canal bed. As an alternative, one may consider a canal lined with concrete within the wetted perimeter x. For further transformations, it is convenient to express the thickness of the lining h_0 as a fraction of the flow depth h:$h_0 = k_0 h$, where k_0 is the transition coefficient from the flow depth to the lining thickness. At the beginning of the calculations, this coefficient can be taken in the range of $k_0 = 0.05 - 0.10$. At the end of the calculations, after the optimal parameters of the canal are found, the lining thickness may be adopted according to the current regulatory documents, and a correction can be introduced into the initial data to repeat the calculation with the corrected concrete lining thickness. Thus, at the beginning of the calculations, the area of the concrete lining – $\boldsymbol{\omega_0}$ in the canal's live cross-section can be determined from the following formula:

$$\omega_0 = h^2(\beta + 2\sqrt{1+m^2})k_0 \tag{9}$$

According to construction standards, the concrete lining is laid on a preparation layer. The thickness of the preparation layer is determined as a fraction of the concrete lining thickness using the transition coefficient $k_t$from concrete works to special earthworks for preparation. At the initial stage of calculations, the transition coefficient can be taken as approximately $k_t = 8 - 10$. Once the thickness of the concrete lining has been determined, the thickness of the preparation layer should be adjusted in accordance with current regulations. Thus, at the beginning of the calculations, in the live cross-section of the flow, the area of the concrete lining with consideration of the preparation layer is taken according to the following relation:

$$\varDelta\omega = h^2(\beta + 2\sqrt{1+m^2})k_1 \tag{10}$$

where $k_1 = k_0(1 + k_t)$.

In the calculations, the additional costs associated with creating a concrete lining in the channel can be considered in two ways. In the first method, the cost of the concrete lining and the preparation layer is added to the cost of the earthworks required for constructing the channel. In the second method, the volumes of the concrete lining and the preparation layer are added to the volume of the earthworks using generalized transition coefficients. The volume of earthworks for constructing a channel in an earthen bed with lining, according to formula (1), is determined as follows:

$$V = \omega l + l^3(i - i_0)^2 m_1/3 + 0.5l^2(i - i_0)B_1 + \varDelta\omega l \tag{11}$$

Equation (11) differs from (1) by the presence of the fourth term $\varDelta\omega l$, which determines the dimensions of the lining with preparation. Let us transform this term using the relationship between the depth h and the area

$$\omega: \varDelta\omega l = h^2(\beta + 2\sqrt{1+m^2})k_1 l = \omega l(\beta + 2\sqrt{1+m^2})k_1/(\beta + m)$$

we obtain

$$V = \omega l + l^3(i - i_0)^2 m_1/3 + 0.5l^2(i - i_0)B_1 + \omega l(\beta + 2\sqrt{1+m^2})k_1/(\beta + m) \tag{12}$$

After a certain period, digging of the bed of the new canal by a single bucket excavator on the route of the old canal started. The bed of the new canal was planned to be built up with concrete pavement. Construction of a concrete-lined canal is accompanied by digging the canal, leveling the slope and bottom of the canal (using a single-bucket excavator), assembling formwork on the bottom and slopes of the canal, and laying a layer of polyethylene on the bottom and slopes of the canal.

In the course of these works, operations on laying concrete coating on the working surfaces of the canal and filling of temperature joints are performed. Of the above operations, the operations on digging the channel and leveling of its slopes and bottom are performed by a single-bucket excavator, and the rest of the operations are performed manually. Ready-mix concrete is delivered to the site by a concrete mixer truck and fed into the channel by a special guide pipe.

3. Results and discussion

It is known that irrigation water is supplied to land plots through temporary inter-farm, on-farm, and small-scale irrigation channels, differing in their sizes. Since the sizes of these canals are different, the equipment used for laying concrete lining in them must also be adapted to the different sizes. Integrated process mechanization is required to reduce the cost of work performed in the fields of land reclamation and water management, road construction and rehabilitation, and to reduce construction time by increasing productivity. To this end, various means of mechanization are used when laying concrete pavements in channels, depending on the size of the channel. With the introduction of such equipment, manual labor is completely eliminated, and work quality and productivity are improved.

Towed and self-propelled pavers are used for concrete paving in channels up to 1.2 m deep. The towed paver is designed for paving inside the finished channel; the paver is towed to a grader or loader. As they are quite light, they can be easily repositioned and pulled out of the canal. Because the canal bed is made according to the design dimensions, there is no need to automatically adjust their heights and forward directions.

The self-propelled compact concrete paver with profiling working element has two or four crawler tracks, depending on the size of the channel. The profiling working element is pulled out of the channel for repositioning and transportation. It is also equipped with automatic adjustment system of its height and forward direction. A conventional conveyor feeder is used to feed the concrete into the working element. A towable concrete paver is used for laying concrete pavements in precisely sized earthen bed channels. They have their own power unit and winch and are not towed.

The large towable paver cannot be lifted by a crane and pulled out of the canal due to its weight. At the front, this paver has a concrete distribution system consisting of a loading conveyor to ensure an even distribution of concrete. Concrete pavement placement in channels with a depth of 1.2–2.4 m is performed using the equipment.

The large, self-propelled, full-profile concrete paver is mounted on two to four crawler tracks. Its height position is automatically adjusted. The machine is also equipped with a loading conveyor, providing an even distribution of concrete in the front part.

The self-propelled concrete paver machine is used for the placement of pavement in distribution and secondary trunk channels. The tractor of the concrete paver machine includes cantilever stands, a power unit, a control system, removable stands, and two or four crawler tracks. The paver machine is equipped with vibrators and a concrete distribution system. To ensure an even distribution of the concrete mix when working in large channels, the loading hopper is equipped with a bucket or scraper conveyor. The concrete mix is poured directly into the hopper from the concrete mixer truck. Special construction is used to adapt small concrete paver machines to the dimensions of the canals. The working element has baffles, vibrators, sliding forms, and a back-running bridge that are installed to prevent the concrete mixture from flowing down slopes. The height and direction of travel of the machine is determined according to the planned surface. No additional equipment is required for the movement of the machine.

Concrete mixture compaction and surface smoothing is required to prevent depressions and cracks from forming and to remove noticeable stone parts during laying of concrete lining. Doing this process manually takes a lot of time. The XD-YQH1600 coating machine manufactured in the Republic of China is a mobile specialized electro-hydraulic construction technique that is widely used. This machine draws, smoothes and compacts concrete cover along the entire perimeter of the canal in one go (figure 4).

The machine places concrete pavement into a finished channel of a trapezoidal cross-section. Its front and back sides are made to match the exact cross-sectional profile of the channel. The manufacturer therefore designs and manufactures the working elements to match the cross-sectional profile of the channel. The machine is used in a completely safe manner. Since the machine is used in the field conditions, it comes with reliable and quality components. In operation, the machine compacts the concrete mix from the hopper after distributing it around the perimeter of the channel while pulling it through the finished channel. Compaction is carried out through a vibrator. Shock absorbers are used to prevent the whole machine from vibrating during compaction. The control system is a simple electrical circuit.

Figure 4. XD-YQH1600 model concrete paver machine

When placing concrete pavements in large canals, a sliding form paver machine manufactured by the American company GOMACO is used (figure 5). GOMACO company equipment is manufactured to meet all operational safety requirements and operates reliably and trouble-free for many years. It is possible to lay a concrete cover in one walk using a trapezoidal sectional formwork, which can be adjusted according to the width, slope and depth of the channel. The sectional mold and front hopper are equipped with various attachments to change the slope and depth of the channel.

Figure 5. Concrete paver machine GP-2600 manufactured by GOMACO company

In order to coordinate all these transitions when working on the construction site, GOMACO engineers provided a series of diagrams with instructions for the width, slope and depth of the channel. The profile of the channel is excavated with excavators, and the chain trimmer mounted on the front of the GP-2600 paver is used to cut the protrusions on the surface of the channel.

4. Conclusion

Preventing water losses caused by seepage in earthen canals is of great importance in ensuring maximum water saving under global warming conditions. For this purpose, the application of concrete lining in earthen canals is considered more appropriate. Concrete lining not only minimizes seepage losses but also increases the durability of the insulation layer and ensures more stable hydraulic conditions. Before the placement of the concrete lining, canals are excavated in earthen beds. At this stage, the natural slope of the terrain must be considered, and the required longitudinal slope of the canal bed should be provided to ensure faster delivery of water to the fields. The excavation of soil is a labor-intensive process, and in this study, its details have been analyzed, and the conditions of optimality have been investigated. The research carried out shows that, at present, no special-purpose concrete paving machines are used for irrigation canals in our republic. However, the use of such machines would not only significantly reduce labor input and the cost of work but also improve the quality and productivity of the technological process of concrete lining in irrigation canals of various sizes.

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Authors' Declaration

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

Authors' Contribution Statement

The entire work was carried out by Akif Gasimov

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