ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

№5
2025

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

5 (473)

SEPTEMBER – OCTOBER 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2025

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News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *Геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*
Мерзімділігі: жылына 6 рет.
http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.
Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*
Периодичность: 6 раз в год.
http://www.geolog-technical.kz/index.php/en/

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NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 5. Number 473 (2025), 173–189

https://doi.org/10.32014/2025.2518-170X.557

UDC 626.81:624.131.23

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EARTHWORKS FOR THE CONSTRUCTION OF AN IRRIGATION CANAL EMBANKMENT USING SANDY SOIL

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Abstract. The reconstruction of the Bustan Canal in the Republic of Karakalpakstan, Uzbekistan, aimed to eliminate the need for pump-based irrigation and transition to gravity-fed irrigation. Additionally, it sought to improve the canal's efficiency by lining its slopes and beds with concrete. A distinguishing feature of constructing such a structure is the ability to use the excavated soil for building the embankment. This significantly reduces construction costs. Field and laboratory studies to determine the physical properties and granulometric composition of the

soils were conducted using standard instruments and equipment by GOST 22733-2002 and GOST 25100-2011 requirements. The soil included loam, sandy loam, and sand. The excavation was carried out with a backhoe excavator, and the soil was deposited along the bank for later use in constructing the embankment. Any additional soil needed was transported from other sites or quarries using dump trucks with capacities of 20 and 40 tons. The removal of the 20 cm thick vegetation layer was performed using a bulldozer and a grader. The base of the embankment was loosened to a depth of 15 cm, and then the soil was leveled using an excavator and a grader. Further moistening was done with a water truck or hose, and the soil was compacted using rollers weighing 18 and 26 tons. The maximum densities achieved for the soils were 1.69-1.89 g/cm³ for loam at an optimal moisture content of 13-17.09%, 1.62 g/cm³ for sandy loam at 21.05% moisture, and 1.62-1.67 g/cm³ for sand at 17.09-21.05% moisture.

Keywords: canal construction, half-cut-half-fill method, soil properties, optimal moisture content, construction equipment

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ҚҰМДЫ ТОПЫРАҚТЫ ПАЙДАЛАНЫП, СУАРУ КАНАЛЫНЫҢ ЖАҒАЛАУЫН САЛУҒА АРНАЛҒАН ЖЕР ЖҰМЫСТАРЫ

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Аннотация. Қарақалпақстан (Өзбекстан) Республикасындағы Бустан каналын қайта жаңарту сорғымен суару қажеттілігін болдырмауға және өздігінен ағатын сумен жабдықтауға көшуге бағытталған. Сонымен қатар, оның беткейлері мен арнасын бетондау арқылы каналдың тиімділігін арттыру қарастырылды. Бұл жобаның ерекшелігі – үйінді салу кезінде қазылған топырақты пайдалану мүмкіндігі, бұл құрылыс шығындарын айтарлықтай төмендетеді. Топырақтың физикалық қасиеттері мен гранулометриялық құрамын анықтау бойынша далалық және зертханалық зерттеулер ГОСТ 22733-2002 және ГОСТ 25100-2011 талаптарына сәйкес стандартты аспаптар мен жабдықтарды пайдалана отырып жүргізілді. Зерттелетін топырақтарға саздақ, құмды саз және құм кірді. Әзірлеуді экскаватор-тиегіш жүргізді, топырақ жағалауда жиналып, кейіннен үйінді орнатуда қолданылды. Қосымша тасымалдау жүк көтергіштігі 20 және 40 тонна самосвалдармен жүзеге асырылды. Қалыңдығы 20 см өсімдік қабатын Бульдозер мен грейдер алып тастады. Үйіндінің негізі 15 см тереңдікке дейін қопсытылды, содан кейін экскаватор мен грейдермен тегістеу жүргізілді, кейін салмағы 18 және 26 тонна роликтермен ылғалдандырылды және тығыздалды. Топырақтың максималды қол жеткізілген тығыздығы 13-17% оңтайлы ылғалдылықта саздақтар үшін 1,69–1,89 г/см3, 21% ылғалдылықта құмды саздар үшін 1,62 г/см3 және 17-21% ылғалдылықта құмдар үшін 1,62–1,67 г/см3 болды.

Түйін сөздер: канал құрылысы, жартылай жартылай толтыру әдісі, топырақ қасиеттері, оңтайлы ылғалдылық, құрылыс жабдықтары

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ГРУНТОВАЯ РАБОТЫ ПО ВОЗВЕДЕНИЮ НАСЫПИ КАНАЛА ИЗ ПЕСЧАНЫХ ГРУНТОВ

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Аннотация. Реконструкция канала Бустан в Республике Каракалпакстан (Узбекистан) была направлена на исключение необходимости насосного орошения и переход на самотечное водоснабжение. Кроме того, предусматривалось повышение эффективности функционирования канала путем бетонирования его откосов и русла. Особенностью данного проекта является возможность использования вынутого грунта при возведении насыпи, что существенно снижает строительные затраты. Полевые и лабораторные исследования по определению физических свойств и гранулометрического состава грунтов проводились с использованием стандартных приборов и оборудования в соответствии с требованиями ГОСТ 22733-2002 и ГОСТ 25100-2011. Исследуемые грунты включали суглинки, супеси и пески. Разработка велась экскаватором-погрузчиком, грунт складировался вдоль берега для последующего использования при устройстве насыпи. Дополнительный подвоз осуществлялся самосвалами грузоподъёмностью 20 и 40 тонн. Растительный слой толщиной 20 см снимался бульдозером и грейдером. Основание насыпи рыхлилось на глубину до 15 см, после чего производилось выравнивание экскаватором и грейдером, последующее увлажнение и уплотнение катками весом 18 и 26 тонн. Максимальные достигнутые плотности грунтов составили 1,69–1,89 г/см³ для суглинков при оптимальной влажности 13–17%, 1,62 г/см³ для супеси при влажности 21% и 1,62–1,67 г/см³ для песков при влажности 17–21%.

Ключевые слова: строительство канала, метод полувыемки-полунасыпи, свойства грунта, оптимальная влажность, строительная техника

Introduction. Filtration reliability is an important factor indicating the efficiency of irrigation systems, including canals constructed in half-cut-half-fill configurations. It ensures that the embankment and foundation maintain their filtration parameters—such as flow rate, velocity, and the position of the depression curve within the calculated values throughout the operational lifespan. This reliability guarantees filtration strength, the absence of slope deformation, soil piping, and suffusion.

Similar cases were analyzed prior to conducting the research. In works (Kadirov and Khasanov 2023), cases of instability of soil embankments in canals were analyzed

depending on various factors. Kiran Prasad Acharya and colleagues conducted a study on the seepage and slope stability modeling of rainfall-induced slope failures in topographic hollows. The calculations were performed using the GeoStudio program, considering pore pressure (Kiran et al, 2016). The reconstruction aimed to reduce filtration within the embankment body, thereby increasing the canal's efficiency coefficient. In article (Rai et al, 2017), the design of earthen canals with a balanced approach to excavation and embankment volumes was examined. In article (Hu and Li 2024), Jiang Hu and Xing Li explored the utilization of the integrated program SHAP-XGB for predicting the stability of slopes in earthen canals undergoing deep excavation. In article (Ashour et al. 2023), Mohamed A. Ashour and colleagues conducted a comparative technical study on estimating seeped water from irrigation canals in Middle Egypt, specifically focusing on the El-Sont branch canal network. They evaluated the volume of filtration through the embankment of canals using Indian calculation methods, which resulted in a 21.5% loss of pressure due to filtration. Chen Zheng and collaborators conducted a field test study on expansive soil canals of the middle route of the South to North Water Diversion Project, focusing on an analytical method for assessing soil deformation in embankments and excavations (Zheng et al, 2023). In reference (Gong et al, 2016), Gong Biwei and colleagues conducted field research in China on a 1200 km-long canal. Part of this canal traverses slopes composed of rocky formations, overlain by loess and loose sands. Jalal Jebelli and Mohamed Meguid conducted a soil stability analysis in irrigation canals, utilizing the SLOPE/W model (Jebelli and Meguid 2013). Doaa A. El-Molla and Mohamed A. El-Molla conducted research on reducing conveyance losses in trapezoidal canals. They utilized the SEEPE/W model to explore filtration issues through compacted earth linings on canal embankments and bottoms (El-Molla D and El-Molla M 2021). Nguyen Dyk Shi, on the other hand, researched ensuring the strength and stability of earth embankments of roads under conditions prevalent in Northern Vietnam (Nguyen 2012). It was obtained by natural experiments and modeling using HEC-RAS 5.0.1 in the Big Fergana Canal, and a roughness coefficient of 0.0199 was determined as a result (Arifjanov et al. 2022).

Iskandar Pani and others investigated the net present value (NPV) of rehabilitating irrigation channels to enhance agricultural production. Their study specifically focused on the reconstruction of an irrigation canal in Indonesia, considering various types of linings such as brick, precast concrete panels, and concrete. They concluded that concrete linings were the most favorable option based on their analysis (Iskandar et al, 2021). Kosichenko and others performed a techno-economic comparison of four alternatives: comprehensive and partial reconstruction, modernization of irrigation systems, and routine maintenance. É.I. Mikhnevich and Zeming Li proposed an analytical method to determine the hydraulically most advantageous cross-section of a canal by reducing the velocity. This reduction in velocity led to a decrease in depth and an increase in the width of the

canal (Mikhnevich and Li 2023). Khyati Mistry and others examined the feasibility of using different types of linings for earthen irrigation canals, considering the reduction in water seepage losses. They identified the type of lining that best suits the canal section based on cost criteria (Mistry 2023). Manasi Jagtap and others highlight the significant role of canals in India's irrigation system. They discussed a project that considers replacing concrete linings with low-density polyethylene (LDPE) sheets and installing solar panels above the canal (Jagtap et al, 2019).

The article (Rao et al, 2024) notes that the choice of calculation schemes for a plane or spatial problem of slope failure, depending on the geometry or loading conditions, is a three-dimensional analysis. In this case, it is important to choose a slip curve that corresponds to the minimum stability coefficient. It is the solutions to this problem that are discussed in this article using the Scoops-3D program. Bishop method (BSM), limit equilibrium method (LEM) was used and digital elevation model (DEM) was used to construct the slope geometry. The results showed that the method allows one to determine the sliding surface of a slope with sufficient accuracy. In research work (Mashayekhi and Khanmohammadi 2024), using 3D numerical models validated by experimental and field data, reveals that while helical piles effectively enhance the bearing capacity of embankments through improved load transfer mechanisms, the helices themselves have a minimal impact on reducing settlement. Experimental testing in a flume model, combined with mathematical simulations using HEC-RAS software, demonstrated that GFRP-lined channels have a Manning roughness coefficient value ranging from 0.0071 to 0.0102, with a recommended practical value of 0.0081, indicating the model's "very good" performance as evaluated by the Nash-Sutcliffe Efficiency method.

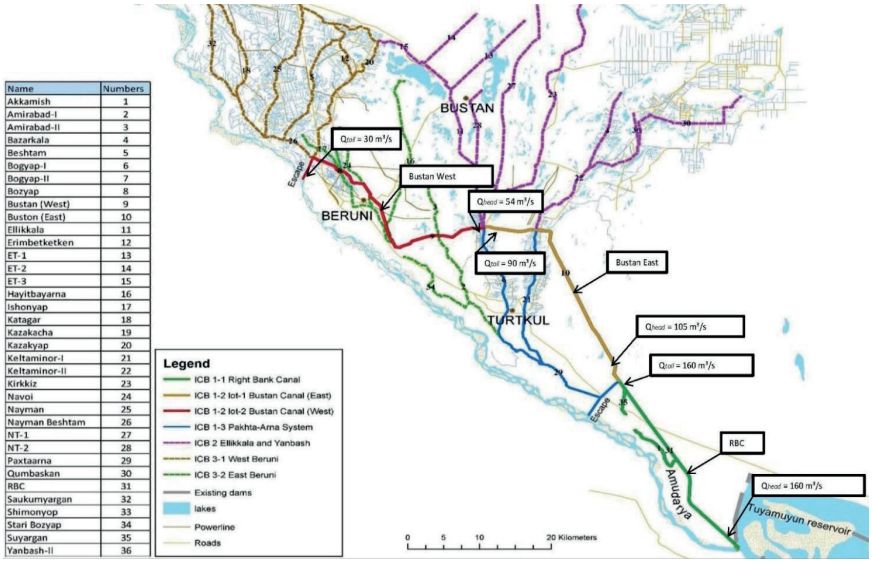
The first article (Espolov et al, 2022) analyzes the structure of river terraces within the Syr Darya basin as part of the Shardara irrigation system. It highlights the issue of compaction in the arable and sub-arable soil layers on irrigated lands. This compaction leads to oxygen deficiency, which subsequently degrades the nutrient content of the soil, negatively affecting its fertility. The second article (Dmitriyev et al, 2024) presents a model for predicting gully erosion using satellite imagery. The model estimates the rate of gully expansion and provides a forecast for the next 30 years. The accuracy of the predictions depends on several factors, including soil density, strength, precipitation levels, and vegetation cover. The third article (Artykbaev et al, 2024) focuses on the development of a method for the placement and compaction of coarse-grained soils. It examines the determination of maximum soil density and optimal moisture content. The method involves placing soil in layers of 50, 70, and 80 cm thickness, compacted using 27-ton rollers with six to eight passes. The process achieves soil densities ranging from 2.11 to 2.28 t/m^3.

The physical properties, particle size distribution, humidity, and density of ash and slag have been established. The experience of using ash and slag as a canal fill is insufficient. GOSTs provide a classification of soils and methods for laboratory studies of optimal moisture content and maximum density.

A brief review of research shows that the problem under consideration in the article is relevant; many issues have been considered and studied during the construction of canals in various weather, climatic and soil conditions.

Materials and methods. The irrigation system of Southern Karakalpakstan is an essential infrastructure supporting agriculture in this arid region. Situated in the lower reaches of the Amu Darya River, Southern Karakalpakstan faces a desert climate with limited rainfall, making irrigation critical for sustaining crop production and livelihoods. One of the main canals in the region, the Bustan Canal is critical in distributing water from the Amu Darya. Its construction was marked by engineering challenges due to the region's topography and soil conditions, such as sand dunes and saline soils. The canal's semi-cut, semi-fill design required innovative solutions, including the use of excavated soil for embankments and the transportation of additional soil to address shortages.

The irrigation system of Southern Karakalpakstan includes three southern districts of the Republic of Karakalpakstan - Turtkul, Ellikkala and Beruni districts and is located on the right bank of the Amu Darya and covers an irrigated area of about 100,000 hectares with a population of 553,900 people. The irrigation network consists of 91 km of interfarm canals (including the Bustan canal) and 550 km of economic canals (Fig. 1).



Name	Numbers
Akkamish	1
Amirabad-I	2
Amirabad-II	3
Bazarkala	4
Beshtam	5
Bogyap-I	6
Bogyap-II	7
Bozyap	8
Bustan (West)	9
Buston (East)	10
Ellikkala	11
Erimbetketken	12
ET-1	13
ET-2	14
ET-3	15
Hayitbayarna	16
Ishonyap	17
Katagar	18
Kazakacha	19
Kazakyap	20
Keltaminor-I	21
Keltaminor-II	22
Kirkkiz	23
Navoi	24
Nayman	25
Nayman Beshtam	26
NT-1	27
NT-2	28
Paxtaarna	29
Qumbaskan	30
RBC	31
Saukumyargan	32
Shimonyop	33
Stari Bozyap	34
Suyargan	35
Yanbash-II	36

Figure 1. Irrigation system of Southern Karakalpakstan

The total length of the Bustan canal is 68.709 km and consists of eastern and western sections, with lengths of 35.26 km and 33.449 km respectively. The flow rates are 105 m^3/s and 49.5 m^3/s respectively. A typical trapezoidal cross-section is shown (Figure 2). The bottom width ranges from 6 to 8 m. The slope inclinations are 1:2.5.

The eastern part of the canal was predominantly constructed on embankments to facilitate control over the irrigated fields, while the western part was partially on embankments and partially in excavation (Fig. 2). The maximum slopes ranged from 0.0001 to 0.00015

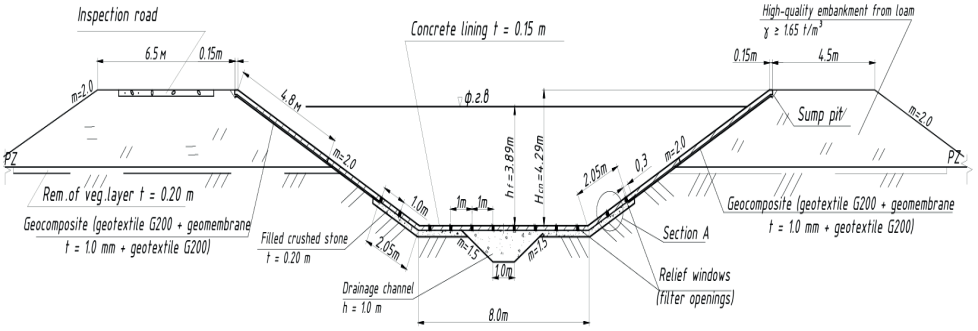


Figure 2. Typical cross-section of the Bustan canal (western section).

Soil analyses were conducted in an accredited construction testing laboratory using the following instruments and equipment: electronic scales CY4112C, drying oven FAITHUL WGI 230B, standard set of sieves KSI, and the Uniondornii device (designed by Kovalev N.P). The physical properties of quarry soils, foundation soils, and embankment soils were determined, including particle size distribution, density, and optimum moisture content, in accordance with GOST 22733–2002 and GOST 25100–2011.

Results and discussion. The distinctive feature of constructing canals in half-cut and half-fill sections is the multitude of quarries and the diversity of physical properties, as well as the particle size distribution of soils. For clarity, some of them are presented in tables. The physical properties of quarry soils are provided in Table 1, and the particle size distribution is given in Table 2. As seen from Table 1, the bulk density of natural moisture soil ranges from 1.61 t/m^3 to 1.65 t/m^3, while that of dry soil ranges from 1.49 to 1.53 t/m^3, with natural moisture content fluctuating from 5.2% to 13.4%.

Table 1. Physical properties of soils

No.	Sampling Location	Excavation No	Volume Weight, t/m^3		Moisture Content of Dry Soil (%)	Soil Name (according to GOST 25100-201), Soil Classification
			Natural Moisture Conte	Moisture Content of Dry Soil		
1	Right embankment, PK 311+70	1	1,63	1,51	5,2	Clay
2	Right embankment, PK 314+00	2	1,65	1,53	9,1	Loam
3	Right embankment, PK 193+00	3	1,63	1,50	5,6	Clay

4	Left embankment, PK 311+65	4	1,61	1,49	13,4	Sand
5	Right embankment, PK 193+00	5	1,62	1,52	9,5	Clay
6	Natural ground beneath concrete, PK 312+55	6	1,61	1,54	8,1	Sand
Norm			1,62	1,51	8,4	

Table 2. Granulometric composition of soils

№	No. Sampling Location	Excavation No	Granulometric composition of soilsin %%, fraction diameter in mm,				Soil Name (according to GOST 25100-201), Soil Classification
			1,0-0,5	0,5-0,25	0,25-0,10	0,10-0,05	
			%	%	%	%	
1	Right embankment, PK 311+70	1	8,6	17,2	71,2	8,48	Clay
2	Right embankment, PK 314+00	2	0,063	2,6	81,07	15,85	Loam
3	Right embankment, PK 193+00	3	0,7	25,7	63,5	10,8	Clay
4	Left embankment, PK 311+65	4	0,6	21,3	58,5	16,7	Sand
5	Right embankment, PK 193+00	5	1,2	13,5	66,8	16,6	Clay
6	Natural ground beneath concrete, PK 312+55	6	1,85	10,2	69,1	15,56	Sand
Norm			2,1	15,08	68,3	13,9	

The particle size distribution (Table 2) shows that fractions ranging from 0.25 to 0.10 mm constitute between 58.53% to 81.07%, while fractions from 0.1 to 0.05 mm constitute between 8.48% to 16.7%. According to the standard (GOST), the soils are classified as loam, clay, and sand. As seen in the table, at almost the same chainage point 311+70, the soils differ between the left and right slopes, with clay on the right and sand on the left.

The density and optimum moisture content of the soil vary along the length of the Bustan canal (western part), ranging from 1.62 g/cm^3 to 1.71 g/cm^3, with the optimal moisture content of clay ranging from 14.07% to 21.05%. For clarity, the test results of samples taken at chainage points 311+70, 314+00, 193+00, and 311+65 are shown (Tables 3-8) (Figures 3-8)

Table 3. Determination of maximum density and optimum moisture for PK 311+70 (Loam). Right slope embankment

Parameters	Unit	Tests						
		1	2	3	4	5	6	7
Shape weight	g	5123	5123	5123	5123	5123	5123	5123
Shape volume	sm^2	996,95	996,95	996,95	996,95	996,95	996,95	996,95
Weight of the cylindrical part of the mold with compacted soil	g	6978	7090	7189	7253	7270	7244	7227
Soil moisture mass	g	1855	1967	2066	2130	2147	2121	2104
Soil moisture density	g/sm^3	1,86	1,97	2,07	2,14	2,15	2,13	2,11
Optimum moisture (%)	%	6	9	11	13	15	17	18
Dry soil density	g/sm^3	1,76	1,81	1,87	1,89	1,87	1,82	1,79
Maximum density	1,89 g/cm^2		Optimum moisture content				13,00%	

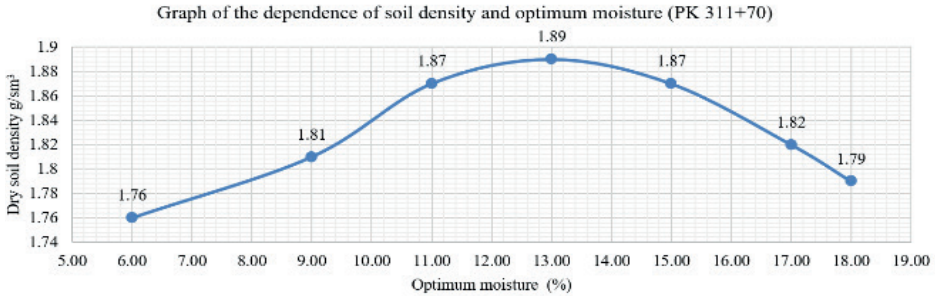


Figure 3. Graph of the dependence of soil density and optimum moisture (PK 311+70)

Table 4. Determination of maximum density and optimum moisture for PK 314+00 (Loam). Right slope embankment

Parameters	Unit	Tests								
		1	2	3	4	5	6	7	8	9
Shape weight	g	5123	5123	5123	5123	5123	5123	5123	5123	5123
Shape volume	sm^2	996,95	996,95	996,95	996,95	996,95	996,95	996,95	996,95	996,95
Weight of the cylindrical part of the mold with compacted soil	g	6763	6810	6874	6960	7010	7082	7122	7168	7160
Soil moisture mass	g	1640	1687	1751	1837	1887	1959	1999	2045	2037
Soil moisture density	g/sm^3	1,65	1,69	1,76	1,84	1,89	1,96	2,01	2,05	2,04

Optimum moisture (%)	%	5	7,2	9,12	11,1	13,21	16,1	18,04	20,12	22,4
Dry soil density	g/ sm^3	1,57	1,58	1,61	1,66	1,67	1,69	1,7	1,71	1,67
Maximum density	1,62 g/cm^2		Optimum moisture content						21.05%	

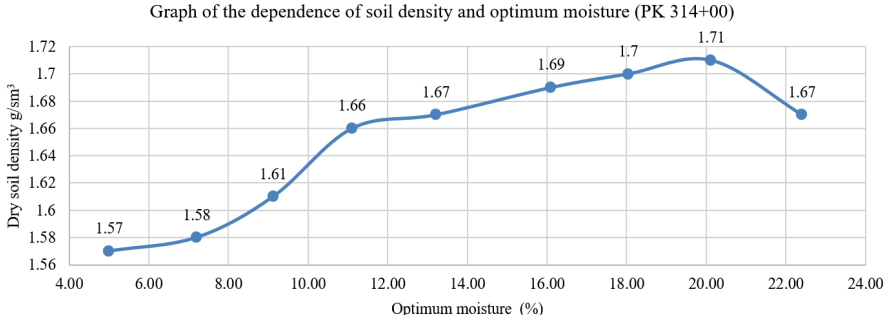


Figure 4. Graph of the dependence of soil density and optimum moisture (PK 314+00)

Table 5. Determination of maximum density and optimum optimum moisture for PK 193+00 (clay). Right slope embankment.

Parameters	Unit	Tests						
		1	2	3	4	5	6	7
Shape weight	g	5123	5123	5123	5123	5123	5123	5123
Shape volume	sm^2	997	997	997	997	997	997	997
Weight of the cylindrical part of the mold with compacted soil	g	6888	7009	7067	7143	7225	7249	7242
Soil moisture mass	g	1765	1886	1944	2020	2102	2126	2119
Soil moisture density	g/sm^3	1,77	1,89	1,95	2,03	2,11	2,13	2,13
Optimum moisture (%)	%	5,11	8,4	10	12,02	14,1	16	18,22
Dry soil density	g/sm^3	1,68	1,75	1,77	1,81	1,85	1,84	1,8
Maximum density	1,69 g/cm^2		Optimum moisture content				14.09%	

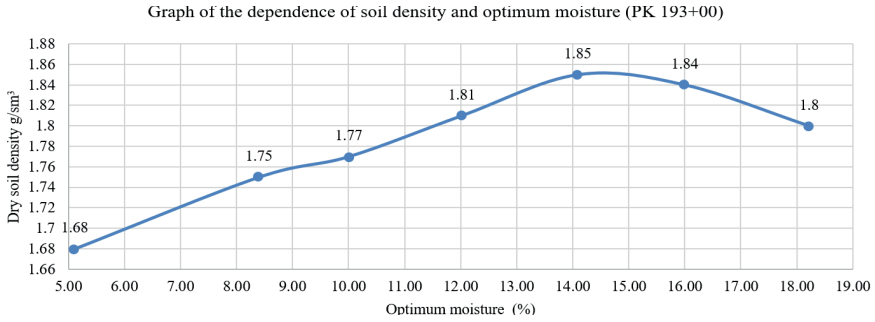


Figure 5. Graph of the dependence of soil density and optimum moisture (PK 193+00)

Table 6. Determination of maximum density and optimum humidity for PK 311+65 (sand) Left slope excavation

Parameters	Unit	Tests							
		1	2	3	4	5	6	7	8
Shape weight	g	5123	5123	5123	5123	5123	5123	5123	5123
Shape volume	sm^2	997	996,95	997	996,95	997	997	997	996,95
Weight of the cylindrical part of the mold with compacted soil	g	6756	6803	6851	6920	6978	7040	7082	7056
Soil moisture mass	g	1633	1680	1728	1797	1855	1917	1959	1935
Soil moisture density	g/sm^3	1,64	1,69	1,73	1,8	1,86	1,92	1,96	1,94
Optimum moisture (%)	%	7,81	9,95	12,17	14,77	17,21	19,08	21,05	22,89
Dry soil density	g/sm^3	1,52	1,53	1,55	1,57	1,59	1,61	1,62	1,58
Maximum density	1,62 g/cm^2		Optimum moisture content				21.05%		

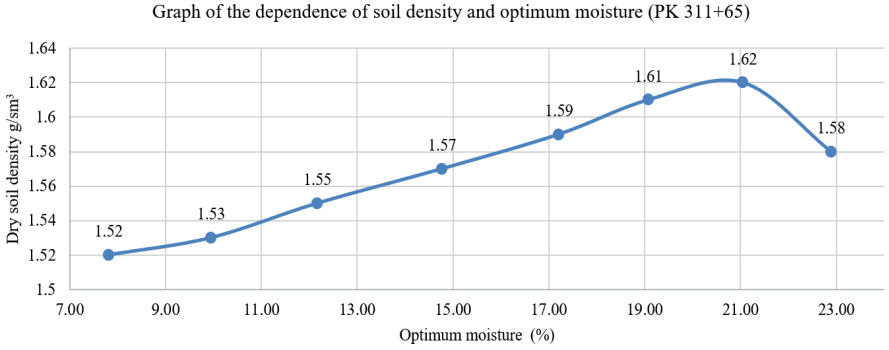


Figure 6. Graph of the dependence of soil density and optimum moisture (PK 311+65)

Table 7. Determination of maximum density and optimum moisture for PK 193+00 (Loam). Right slope excavation

Parameters	Unit	Tests								
		1	2	3	4	5	6	7	8	9
Shape weight	g	5123	5123	5123	5123	5123	5123	5123	5123	5123
Shape volume	sm^2	997	997	997	997	997	997	997	996,95	996,95
Weight of the cylindrical part of the mold with compacted soil	g	6794	6834	6878	6937	6993	7049	7078	7108	7099
Soil moisture mass	g	1671	1711	1755	1814	1870	1926	1955	1985	1976
Soil moisture density	g/sm^3	1,68	1,72	1,76	1,82	1,88	1,93	1,96	1,99	1,98
Optimum moisture (%)	%	6,63	7,76	9,48	11,37	13,4	14,83	15,71	17,09	18,57

Dry soil density	g/sm³	1,57	1,59	1,61	1,63	1,65	1,68	1,69	1,7	1,67
Maximum density	1,70 g/cm²		Optimum moisture content						17.09%	

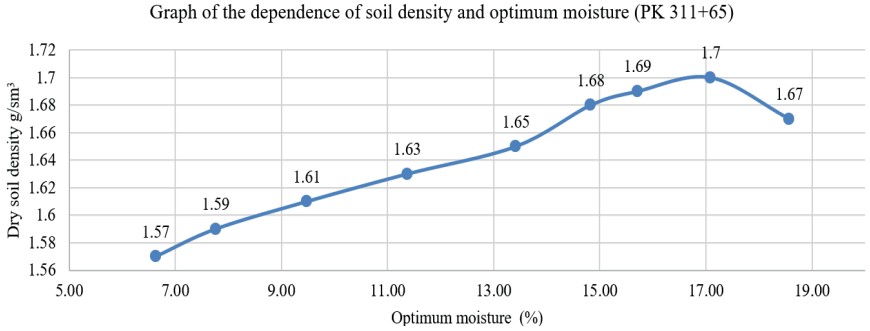


Figure 7. Graph of the dependence of soil density and optimum moisture (PK 311+65)

Table 8. Determination of maximum density and optimum moisture for PK 312+55 (Sand). Right slope excavation

Parameters	Unit	Tests										
		1	2	3	4	5	6	7	8	9	10	11
Shape weight	g	5128	5128	5128	5128	5128	5128	5128	5128	5128	5128	5128
Shape volume	sm²	997	996,95	997	996,9	997	997	997	996,9	996,9	996,9	996,9
Weight of the cylindrical part of the mold with compacted soil	g	6760	6802	6841	6896	6946	6984	7029	7062	7100	7092	7076
Soil moisture mass	g	1632	1674	1713	1768	1818	1856	1901	1934	1972	1964	1948
Soil moisture density	g/sm³	1,64	1,68	1,72	1,77	1,82	1,86	1,91	1,94	1,98	1,97	1,95
Optimum moisture (%)	%	6,27	7,68	9,4	11,53	13,77	14,98	16,15	17	18,47	19,54	20,61
Dry soil density	g/sm³	1,54	1,56	1,57	1,59	1,6	1,62	1,64	1,66	1,67	1,65	1,62
Maximum density	1,67 g/cm²		Optimum moisture content						17.09%			

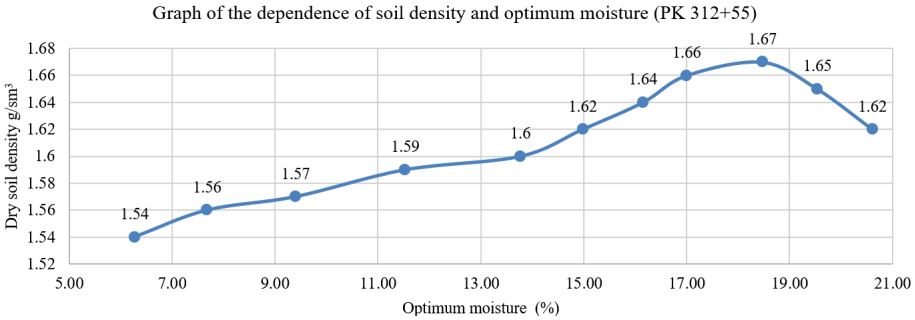


Figure 8. Graph of the dependence of soil density and optimum moisture (PK 312+55)

The determination of maximum density and optimum moisture content for various soil types at different points along the canal reveals crucial information for the construction and stability of embankments and excavations. The density and optimum moisture content of the soil vary along the length of the Bustan canal (western part), ranging from 1.62 g/cm3 to 1.71 g/cm3, with the optimal moisture content of clay ranging from 14.07% to 21.05%. For clarity, the test results of samples taken at chainage points 311+70, 314+00, 193+00, and 311+65 are shown (Tables 3-8) (Figures 3-8). For loam at PK 311+70 and PK 314+00, the maximum dry densities are 1.89 g/cm³ and 1.62 g/cm³ with optimum moisture contents of 13.00% and 21.05%, respectively. At PK 193+00, clay exhibits a maximum dry density of 1.69 g/cm³ with an optimum moisture content of 14.09%, while loam on the right-side excavation shows a maximum dry density of 1.70 g/cm³ at 17.09% moisture. Sand at PK 311+65 and PK 312+55 has maximum dry densities of 1.62 g/cm³ and 1.67 g/cm³ with optimum moisture contents of 21.05% and 17.09%, respectively. These results indicate the importance of maintaining specific moisture contents to achieve maximum soil density, ensuring the structural integrity of the canal's slopes and embankments, with each soil type requiring precise moisture control during construction.

According to the design marks, the axis of the channel and the side piles were designated. During the preparation of the foundation, trees and shrubs were uprooted using a root plow to a depth of up to 0.9 meters where necessary. The cutting of the vegetative layer to a depth of 0.20 meters was carried out using a bulldozer, and the removed material was transported outside the construction site. Then, excavation of the soil (Fig. 9) was carried out using an excavator, and the excavated soil was piled along the channel to serve as material for embankment construction (Fig. 10).

Figure 9. Bulldozer cutting through the vegetative layer

Figure 10. Excavation using an excavator and stacking soil along the channel.

After completing the vegetation clearance, a geodetic survey of the foundation for the embankment was conducted. The surface of the ground was loosened to a depth of 0.15 meters to ensure bonding between the embankment and the foundation, followed by leveling the soil using an excavator (Fig. 11). Any deficient soil was brought in by dump trucks (Fig. 12).

Figure 11. Leveling of the soil using an excavator

Figure 12. Delivery of soil by dump trucks

Using watering machines or manually, it was moistened to optimal humidity and then compacted (Fig. 13). Then samples were taken for density (Fig. 14), which were carried out in an accredited laboratory or field conditions using a Kovalov density meter-moisture meter (Fig. 15), the density of the soil was determined which varied 1.51 -1.59 t/m3 at a humidity of 20% to 22%, which is higher than in the project 1.5 - 1.55 t/m3.

Figure 13. Moistening the soil to the optimum moisture level (machines and manually)

Figure 14. Density samples

Figure 15. Kovalov density-moisture meter

Conclusions. Bustan Canal plays an important role in supplying water to 100,000 hectares of farmland in Southern Karakalpakstan. Reconstruction of the canal allows you to abandon expensive irrigation using pumps and switch the system to gravity irrigation, and due to concrete fastening, an increase in the efficiency of the canal up to 85% is achieved.

In the western part, the canal runs in a half-cut-half-fill and intercepts groundwater and filtration water, as a result of which a decrease in the groundwater level in adjacent areas is achieved, as well as a reduction in construction costs.

For the construction of the embankment, mainly excavated soil was used and, if there was a shortage, quarry soil, which was represented by loam, sandy loam and sand. The embankment was erected layer by layer with a thickness of 15 cm using excavators, graders, watering machines, dumping.

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www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Ответственный редактор *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Т. Апендиев*
Верстка на компьютере: *Г.Д. Жадырановой*

Подписано в печать 15.10.2025.
Формат 70x90$^{1}/_{16}$. 20,5 п.л.
Заказ 5.

«Central Asian Academic Research Center» LLP
Алматы, Қонаев к-сі, 142