https://technobius.kz/

e-ISSN 2789-7338

Technobius

A peer-reviewed open-access journal

Technobius, LLP

Volume 2, No. 3, 2022

Technobius

Volume 2, No. 3, 2022

A peer-reviewed open-access journal registered by the Ministry of Information and Social Development of the Republic of Kazakhstan, Certificate № KZ00VPY00039799 dated 7.09.2021

ISSN (Online): 2789-7338
Thematic Directions: Construction and Materials Science
Publisher: Technobius, LLP
Address: 17A Momyshuly street, office 22, 010000, Astana, Republic of Kazakhstan

Contacts:
Website: https://technobius.kz/
E-mail: technobius.research@gmail.com

CONTENTS

Technobius, 2022, 2(3), 0021, DOI: https://doi.org/10.54355/tbus/2.3.2022.0021

Technobius

https://technobius.kz/

e-ISSN 2789-7338

Article

Computer-aided calculation of the volume of soil masses using Civil 3D

Ramil Timirkhanov[1], Shyngys Zharassov[1,*], Nursultan Baltabekov[1], Aleksej Aniskin[2]

[1]L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan
[2]Department of Civil Engineering, University North, Varaždin, Croatia
*Correspondence: zhshzh95@gmail.com

Abstract. Accuracy and automation of processes in all areas of human activity play a significant role, so new technologies are increasingly replacing human labor. In all this variety of IT solutions, the logic is more and more rarely traced in the absence of calculation methodology with a combination of necessary tools. This article describes one way of calculating the volume of soil masses using Civil 3D software. As a result of comparison of traditional and automated methods of calculation of volume of earth masses, the essential difference both in total values, and in the time spent for calculations has been revealed. A parallel between surplus volumes and freight transport logistics was drawn. The described method of calculating the volume of soil masses makes it possible to visually estimate the work front, select a suitable method of excavation works, develop production organization, take into account the need for soil removal and filling, determine the cost and duration of excavation works.
Keywords: Civil 3D, Geodesy, Surveying, Automation, Topographic mapping

1. Introduction

The management of all construction processes is based on precision. It covers all phases of the construction process, from project initiation to full completion. The elements are generally considered to be the levels, planes and axes that are defined in the design in a given site. Any deviation from these parameters is fraught with serious consequences [1]. Often deviations appear due to the human factor. For this reason, every process requires automation in management. Automation is achieved through the continuous improvement and implementation of new technologies, especially IT [2]. Not all areas of human activity are being automated or digitized so quickly, but there is a trend, which can be observed in the construction industry. Touching the topic of calculation accuracy, which is an important factor for other industries as well, construction occupies a large part of it [3], since strategically important projects require an appropriate building or structure. The problem is reflected in the implementation of such projects. The increase in the cost of some work in the early stages of construction is very expensive and in this case, the use of new technologies can reduce costs and time during construction.

Based on the above, the early stage of design requires special accuracy, as at this stage all the necessary design documentation for the project is formed. The required accuracy is determined by means of given coordinates, which in turn require a number of competent engineers, tools, and methods for constructing horizontal and vertical planes, and calculating planned and actual volumes of soil masses. Competence in this area falls within the functional area of responsibility of the people performing the geodetic surveys, i.e., the geodetic engineer. A specialist in this field should be very versatile, as the determination of coordinates and heights of points of the earth's surface require both theoretical and practical skills of applying calculations and the use of modern technology. Therefore, based on the importance of geodetic survey coverage, there exist a number of software solutions to automate and manage the functional area of responsibility of this engineer at the construction site [4].

A number of software products are available on the IT market that simplify and speed up the production processes during surveying (Table 1). The mathematical data processing and field measurements are fundamental to the software used in geodesy. Existing software can be divided into blocks used specifically for one task or complexes that consider calculations as a whole [1].

Table 1 – Types of geodetic surveying and their application

№	Types	Application
1	Topographic survey	Topographic plans and maps
2	Tachymetric survey	Determining the points location on a plane and elevation
3	Horizontal survey	Drawing a contour map of the earth's surface
4	Vertical survey (altitude)	Creation of cartographic maps showing the terrain relief

A simple example is using Excel spreadsheets. Despite the limited visual component, the range of applications of this tool is very large, such as the calculation of forward and reverse surveying, processing of theodolitic and leveling work, determination of areas and deviation from the project planes, as well as the determination of volumes and many other applied tasks [5]. This method is semi-automated and an incorrectly entered algorithm can lead to some errors. For this reason, there are specialized software to reduce the risks arising in the presence of the human factor. Among the domestic developments of the CIS countries, the line of products of the Belarusian company's Credo-Dialog with the Credo program complex of the same name is widely distinguished. The complex includes such modules as Credo-leveling, Credo-deformation calculation, Credo-topoplane and many other extensions [6]. Autodesk product lines such as AutoCAD, Civil 3D, and Map 3D are popular in Europe and overseas [7]. It is worth noting that the capabilities of this product line of Autodesk are quite wide as they combine all kinds of existing tools for geodetic activities, from linking with Excel spreadsheets to surface modeling and working with point clouds. In addition to software, it is possible to allocate design and geodetic platforms that are based on applications of Autodesk corporation. The purpose of project-geodesic platform is to adapt foreign developments to domestic technologies and standards. One of such modules is GeoniCS-surveyor, with the help of which processing of different types of measurements, designing, alignment and error detection, catalogs forming, calculations, data export and import can be performed. There are also highly specialized software programs that solve the problem much faster and more accurately than complex programs that require more in-depth knowledge and Agisoft PhotoScan is a proof of that. Being essentially an autonomous software product it can perform photogrammetric processing of digital images and create three-dimensional spatial data for use in GIS [8].

Thus, apart from accuracy, which is a mandatory requirement, the use of some or other software in geodesy depends on the technical assignment, the level of competence of specialists and the timing of the planned tasks. In general, the above-mentioned software is only a tool in the hands of an experienced specialist, where the main factor remains only the speed and accuracy of achieving results [9]. Consequently, a judiciously chosen combination of tools involves achieving them quickly than the established traditional methods [7-10]. The only traditional method of counting is known, but for each geometric figure, i.e., constructive, it is different. Under the constructive, there are excavations, trenches and embankments. Constructivities are found in aggregate for this reason the figures are broken down into several simpler and more regular geometric bodies, and then their volume is summed up [11]. If we go deeper into the general systematic execution of the traditional method, we can highlight the following:

- Availability of a geodetic substrate with a vertical layout of the building site at a certain scale;
- Drawing a grid of squares where black (real), red (assumed) and working marks, which mean the difference between the existing and project data, are located in the corners;

- Determining the marks on the tops of the squares according to embankment and excavation, plus or minus, respectively;
- Tracing the uniform change in height, followed by connecting the obtained points to each other;
- Marking the lines of zero works, defining the area between the excavation and embankment.

In this regard, the authors formulated the purpose of this article, to present a version of the execution of the topographical survey on the example of calculating the earth mass of the site for the construction of a multi-storey residential complex within the city, where instead of the traditional method a fully automated method with minimal labor and time is applied.

2. Methods

The methodology proposed by the authors for calculating the volume of earth masses is applicable in the case of engineering network design, excavation development, landscaping, vertical planning of a land plot. In all this, the scope of application of the methodology is not limited to carrying out construction works and can be extended to such works as monitoring of mining operations and any other types of excavation works [12].

The volume of soil masses is taken as the difference between two surfaces on the basis of the topographic survey with the use of tools determining the initial coordinates of points relative to the level of the Baltic Sea [13].

The method of calculation begins with an AutoCAD file with the extension .dxf, obtained after the Tachymeter survey, where all the data is distributed by layers. Based on these data the earth masses cartogram with the relief image in the form of horizontals with a grid of squares is built. The grid of squares contains black and red working marks with intersecting lines of zero works. The resulting topographic survey was imported from the LEICA TS03 R500 Total Station into standard AutoCAD (Figure 1). This residential complex called "Besterek - 3" is located on the left bank of Nur-Sultan on Fariza Ongarsynova Street and has been successfully commissioned.

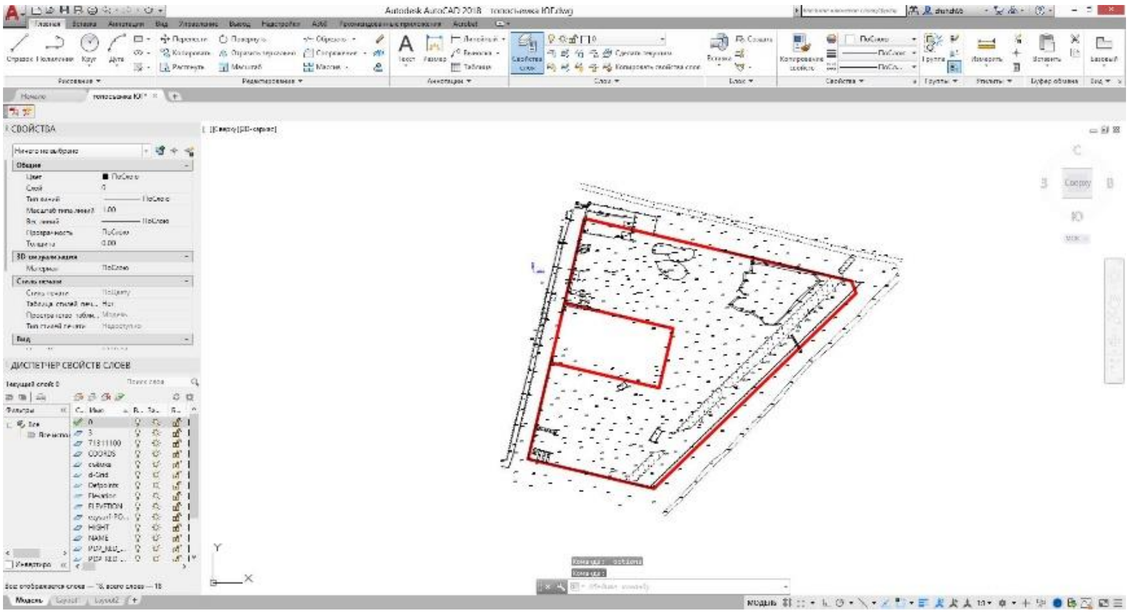

Figure 1 – Construction site tachymetric survey in AutoCAD

Then, all the data in the original coordinates were transferred to the Civil 3D environment, where the corresponding modules for the automated calculation were used. The automated calculation consists of data analysis modules using drawing area tools, which include points, point groups and surfaces (Figure 2).

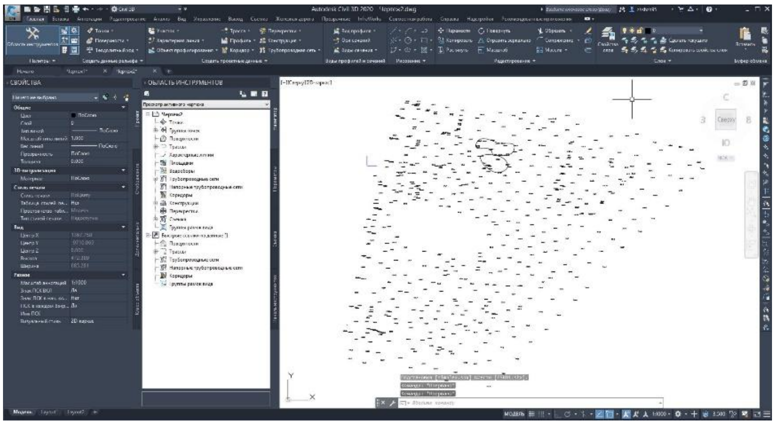

Figure 2 – Construction site tachymetric survey in Civil 3D

To process initial data into Civil 3D point format it is necessary to remove unidentified objects for further calculation. Unidentified object is any text except for point values and complex primitives that consist of one or more interconnected rectilinear and arc segments representing a single object, such as polylines and excavation boundaries. However, there are also calculations based on polylines, but in this case the calculation using specific points is applied [14]. In the case of Civil 3D, the polyline is only needed to build surface boundaries (Figure 3).

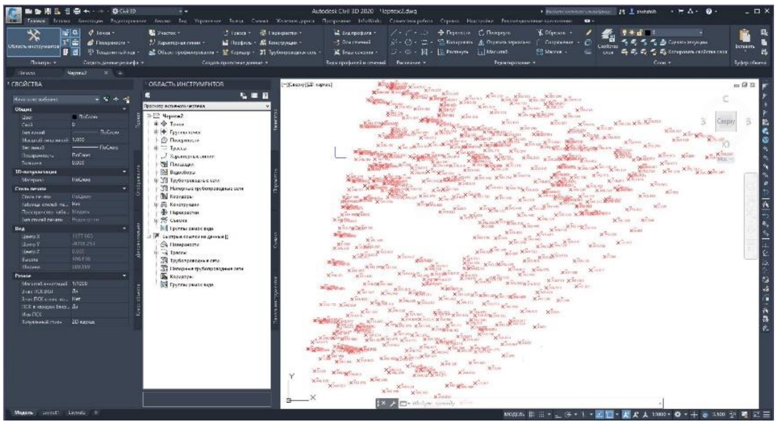

Figure 3 – Tachymetric survey of a construction site for processing in Civil 3D without primitives with the necessary data

After determining the desired points with the initial coordinate data, 2 surface boundaries are drawn for their subsequent comparison. The defined boundaries are drawn with a polyline and the points that are on the boundary of the design elevation transition, defining the construction area, take the following form, shown in Figure 4. The designation may be different depending on the user's settings.

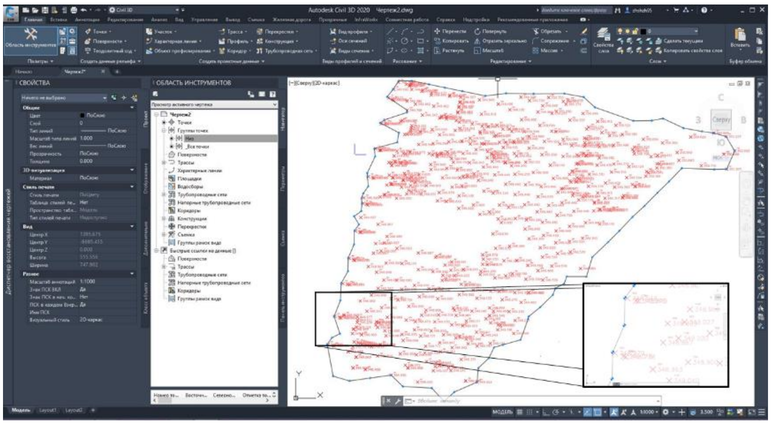

Figure 4 – Delineation of surface plotting boundaries in Civil 3D

During data preparation for analysis, there may be system errors that may occur during data transfer. One of such moments is frequent error of definition of a point outside the initial coordinates, which is tied to zero in the working environment of 3D model. The error is solved by excluding the detected points by a given condition of marks exceeding the mark zero in the working environment (Figure 5).

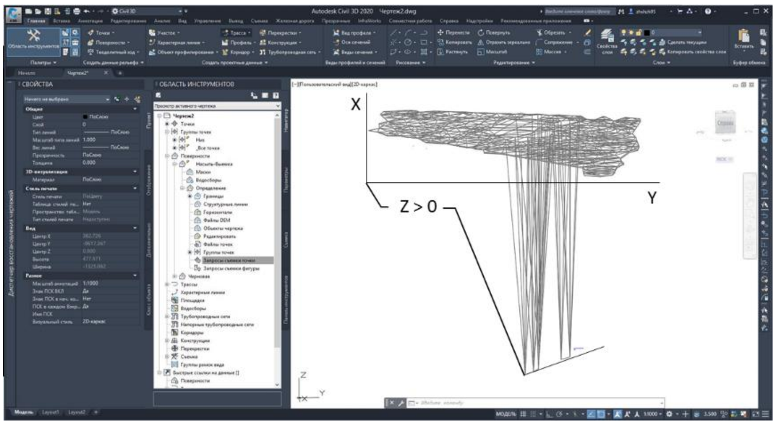

Figure 5 – Error in determining points outside the initial coordinates in the Civil 3D environment

The finite element grid built from the processed data provides an opportunity for evaluating the vertical layout if the existing topography of the construction site does not meet the requirements (Figure 6).

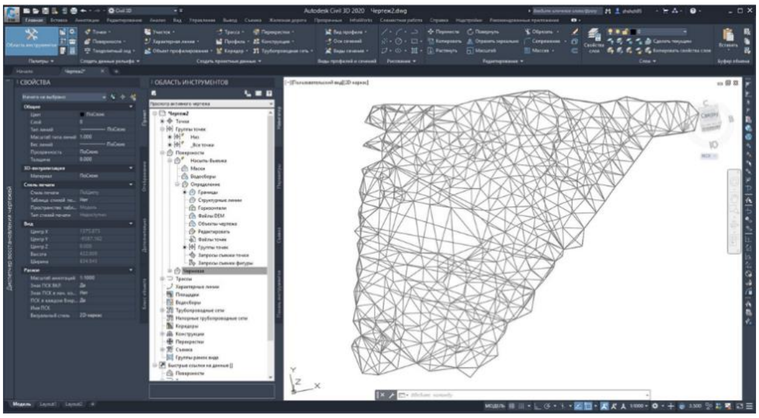

Figure 6 – Finite element grid in the Civil 3D environment

Further visualization of the grid clearly shows where soil cutting or replenishment is required (Figure 7).

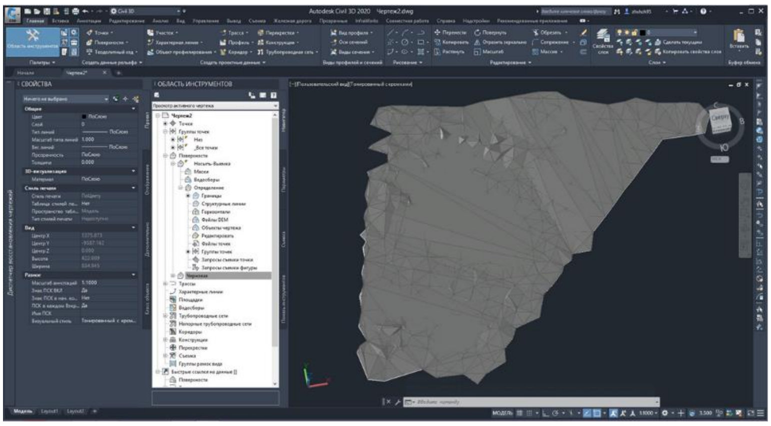

Figure 7 – Visualization of vertical planning in the Civil 3D environment

On the basis of the resulting 3D model, you can perform a calculation where given surfaces by comparing the excess volumes in one degree or another form the black and red working marks on the map of earth masses.

3. Results and Discussion

The comparison of traditional and automated methods of calculating the volume of earth masses revealed a significant difference, both in the final values and in the time spent on the calculations.

The difference found when comparing the two versions of the calculations, gives a clear picture of the losses at the construction site, because if the total difference in the soil to translate the number of special equipment for its transportation, it comes out 17 trucks of 80 tons each. For small projects this may not be significant, but for large-scale projects the losses are very large (Figure 8, Table 2).

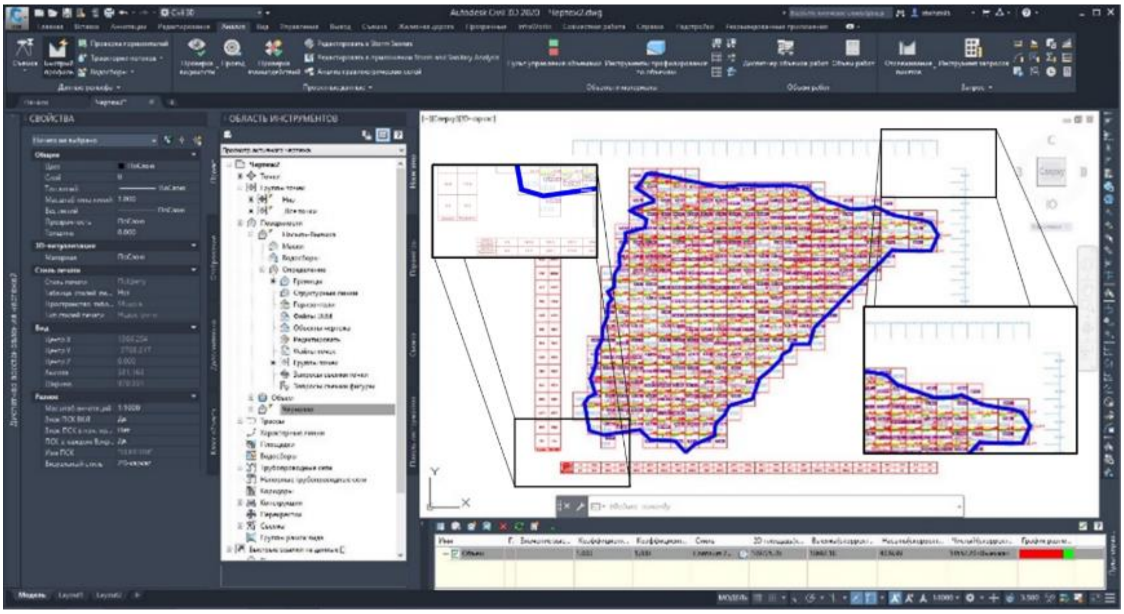

Figure 8 – Calculation by grid method of vertical leveling in the Civil 3D environment

Table 2 – Comparison of traditional and automated calculation of the volume of soil masses of the vertical leveling of the construction site in the Civil 3D environment

№	Indicator	Traditional calculation		Automated calculation		Deviation	
		Filling	Removing	Filling	Removing	Filling	Removing
1	Volume, m3	7873	301	6594.85	396.79	1278.15	-96.79
2	Time spent, hours	1.5		0.5		1.0	
					Total, m^3	1374.94	

It is possible to continue the method of calculating the volume of earth masses using autonomous software, for example Agisoft PhotoScan [15]. The positive side of the use of such software is the independence and adaptation to different systems. In this case, the main tool is an unmanned aerial vehicle (UAV) to obtain high-quality images for further photogrammetry.

4. Conclusions

The authors of the article present a technique for automating the calculation of the volume of earth masses using Civil 3D software, which allows:

1. Visually assess the work front.

2. Select a suitable method of excavation works;
3. To work out the organization of production;
4. Take into account the need for removal of soil and formation of embankments;
5. Determine the cost and duration of earthworks.

References

1. Planning and Implementation of Construction Investments - The Basic Stage of Works / K. Noga // Civil and Environmental Engineering Reports. — 2021. — Vol. 31, No. 4. — P. 184–195. https://doi.org/10.2478/ceer-2021-0056
2. Efficiency optimization and quality control of engineering geodesy processes in civil engineering / V. Berkhahn, F. Berner, H. Kutterer, V. Schwieger, J. Hirschner, I. Rehr, N. Rinke, J. Schweitzer // BAUINGENIEUR. — 2010. — Vol. 85. — P. 491–501.
3. UAS Point Cloud Accuracy Assessment Using Structure from Motion–Based Photogrammetry and PPK Georeferencing Technique for Building Surveying Applications / J.G. Martinez, G. Albeaino, M. Gheisari, W. Volkmann, L.F. Alarcón // Journal of Computing in Civil Engineering. — 2021. — Vol. 35, No. 1. — P. 05020004. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000936
4. Geodäsie im Investitionsbauprozess auf den Bahngebieten in Polen / A. Kampczyk // Bautechnik. — 2014. — Vol. 91, No. 6. — P. 409–413. https://doi.org/10.1002/bate.201300105
5. Web-Based Architecture for Automating Quantity Surveying Construction Cost Calculation / J.H. Yousif, S.N. Abdul Majeed, F.J.I. Al Azzawi // Infrastructures. — 2020. — Vol. 5, No. 6. — P. 45. https://doi.org/10.3390/infrastructures5060045
6. CREDOS: A Conservation Reserve Evaluation and Design Optimisation System / N.D. Crossman, L.M. Perry, B.A. Bryan, B. Ostendorf // Environmental Modelling & Software. — 2007. — Vol. 22, No. 4. — P. 449–463. https://doi.org/10.1016/j.envsoft.2005.12.006
7. Peculiarity of Software selection for training of landscape design / V.F. Shpagin // Information Technologies and Learning Tools. — 2018. — Vol. 68, No. 6. — P. 181–192. https://doi.org/10.33407/itlt.v68i6.2152
8. Assessing the performance of commercial Agisoft PhotoScan software to deliver reliable data for accurate3D modelling / A. Jebur, F. Abed, M. Mohammed // MATEC Web of Conferences. — 2018. — Vol. 162. — P. 03022. https://doi.org/10.1051/matecconf/201816203022
9. UAV and the comparison of image processing software / D. Kaimaris, P. Patias, M. Sifnaiou // International Journal of Intelligent Unmanned Systems. — 2017. — Vol. 5, No. 1. — P. 18–27. https://doi.org/10.1108/IJIUS-12-2016-0009
10. Performance comparison analysis of 3D reconstruction modeling software in construction site visualization and mapping / A. Keyvanfar, A. Shafaghat, M.S. Rosley // International Journal of Architectural Computing. — 2022. — Vol. 20, No. 2. — P. 453–475. https://doi.org/10.1177/14780771211066876
11. Interstate standard GOST 21.508-93. System of building design documents. Rules of fulfilment of working documentation of general layouts of enterprises, buildings and civil housing objects.
12. The Accuracy of Low-Altitude Photogrammetry of Drones / N. Guo, Y. Li // International Journal of Pattern Recognition and Artificial Intelligence. — 2020. — Vol. 34, No. 08. — P. 2059029. https://doi.org/10.1142/S0218001420590296
13. Ob utverzhdenii Pravil organizacii zastrojki i prohozhdeniya razreshitelnyh procedur v sfere stroitelstva [Electronic resource] / adilet.zan.kz. — [2015]. — Mode of access: https://adilet.zan.kz/rus/docs/V1500012684 (accessed date: 19.08.2022).
14. An Algorithm of Offsetting Complex Region Based on AutoCAD / F. Gao // 2008 International Symposium on Computer Science and Computational Technology. — Shanghai, China: IEEE, 2008. — P. 648–651. https://doi.org/10.1109/ISCSCT.2008.348
15. Assessing the Accuracy of High Resolution Digital Surface Models Computed by PhotoScan® and MicMac® in Sub-Optimal Survey Conditions / M. Jaud, S. Passot, R. Le Bivic, C. Delacourt, P. Grandjean, N. Le Dantec // Remote Sensing. — 2016. — Vol. 8, No. 6. — P. 465. https://doi.org/10.3390/rs8060465

Information about authors:

Timirkhanov Ramil – MSc Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan, romaversache@mail.ru

Shyngys Zharassov – PhD Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan, zhshzh95@gmail.com

Nursultan Baltabekov – MSc Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan, bna0575@gmail.com

Aleksej Aniskin – Candidate of Technical Sciences, Assistant Professor, Department of Civil Engineering, University North, Varaždin, Croatia, aaniskin@unin.hr

Author Contributions:
Timirkhanov Ramil – concept, resources, drafting, testing.
Shyngys Zharassov – methodology, modeling, analysis, funding acquisition.
Nursultan Baltabekov – data collection, visualization.
Aleksej Aniskin – interpretation, editing.

Received: 20.08.2022
Revised: 01.09.2022
Accepted: 01.09.2022
Published: 01.09.2022

Technobius, 2022, 2(3), 0022, DOI: https://doi.org/10.54355/tbus/2.3.2022.0022

Technobius

https://technobius.kz/

e-ISSN 2789-7338

Article

Study of cement binders applicable for modified cast-in-place concrete

Khaidi Khonjo, Yerzhan Toleuov, Aizere Azbergenova, Akkumis Urumbayeva

Department of Construction and Building Materials, Satbayev University, Almaty, Kazakhstan
*Correspondence: hhonjo0809@gmail.com

Abstract. This article presents the results of experimental studies of cement binder from local raw material bases optimal for the production of cast modified concrete (CMC). Having a special self-compacting nature, as well as a sensitive cost-effectiveness for the Kazakhstan concrete mixtures manufacturer, this type of concrete requires the use of cement with stable physical and technical characteristics. The study conducted an analysis of the nomenclature of local bases of cement raw materials, testing for cement fineness of Portland cement PC 400 D20 and compressive strength. It is revealed that in Kazakhstan there is a fairly wide range of cement products available with and without additives, produced by dry and wet method. Samples of Portland cement with mineral additives were taken for testing. According to the results of tests, the best indicators of grinding fineness 94.65% and compressive strength on 28 days 42.8 MPa were obtained for Portland cement with mineral additives of Bukhtarminskaya cement company LLP, produced by wet method.
Keywords: CMC, cement binder, Portland cement, compressive strength, raw materials.

1. Introduction

Modern monolithic house-building requires the use of an expanded range of commercial concrete products. In this regard, plants producing concrete mixtures are continuously engaged in optimization of the production process, involving leading concrete scientists, and implementing the results of their scientific and scientific-technical works [1-2]. For example, the authors of this study were faced with a number of applied problems, which allowed the plant Temirbeton-1 LLP (Almaty, Kazakhstan) to diversify its production. Diversification was subjected to the technological line of production of the widely used in Kazakhstan heavy concrete grade M350 class B25. The works were aimed at selection of compositions and development of cast modified concrete (CMC) technology. According to the literature, CMC is associated with the so-called self-compacting concrete (SCC). This concrete has a number of useful qualities, the main of which is the ability to compact under the action of its own weight [3]. The first steps in this direction were made by Japanese scientists in the 1980s. Since then, a lot of its modifications have been proposed, including the use of mineral additives from heavy industry waste [4-5]. Despite the fact that there have been many studies on CMCs, because of regional specifics, this area is still relevant, especially in Kazakhstan [6-7]. After all, an important factor determining the properties and quality of concrete and concrete mixes, as well as the continuity of their production is the availability of high-quality raw materials from local bases (as transportation of raw materials from abroad is likely to be unprofitable). Dynamic development of building materials market has a significant impact on the quality of raw materials supplied for concrete, necessitating continuous monitoring of their characteristics. And since cement is fundamental among them, control of its physical and technical characteristics requires special attention [8].

Portland cements with mineral additives not more than 20% by composition are accepted as binders for CMC [9], as other binders of cement group have a narrow focus of use. Mineral additives (e.g., fly ash) have a positive effect on the CMC, providing water retention and low segregation of the concrete mixture [5]. The main physical and technical properties of Portland cement, which should be paid keen attention to are the fineness and compressive strength at 28 days of hardening.

In this study the authors performed a comparative analysis of the basic properties of cement binder for CMC, presented by various manufacturers of local raw materials; considered the range of cement presented in the market and its physical and technical characteristics by conducting experimental studies.

2. Methods

To date, the leading manufacturers of cements in Kazakhstan that meet the requirements of [9] and [10] are:

1) "HeidelbergCement" group of companies (Heidelberg, Germany) [11], represented in Kazakhstan by the following organizations with a total staff of about 2,000 employees: plants of "Bukhtarminskaya cement company" LLP (Ust-Kamenogorsk); "Caspicement" LLP (Mangistau region); and "Shymkentcement" JSC (Shymkent); dealers and partners "Baykaz concrete" LLP (Almaty) and "Bektas group" LLP (Almaty), and others. Activity of HeidelbergCement is mainly connected with production and sale of cement, ready-mix concrete and aggregates. The list of products manufactured by these plants is given in Table 1 below.

Table 1 – Nomenclature of HeidelbergCement products in Kazakhstan [11]

Product name	Brand	Standard	Production type
Bukhtarminskaya cement company LLP (wet production)			
Portland cement with mineral additives	CEM II/A-S 42.5 H	GOST 31108-2003	Serial
	CEM II/A-S 32.5 H	GOST 31108-2003	On request
	CEM II/A-I 32.5 H	GOST 31108-2003	On request
Portland cement	PC 400-D20	GOST 10178-85	Serial
	CEM I 42.5 H	GOST 31108-2003	Serial
	PC 500 D0	GOST 10178-85	Serial
	PC 400 D0	GOST 10178-85	Serial
Portland cement of normalized composition	PC 500 D0-H	GOST 10178-85	Serial
	PC 400 D0-H	GOST 10178-85	On request
Portland sulfate-resistant cement	CEM I 42.5 H CC	GOST 22266-2013	Serial
Portland sulfate-resistant low-alkaline cement	CEM I 42.5 H CC NS	GOST 22266-2013	Serial
Composite cement	CEM V/A (S-P) 32.5 H	GOST 31108-2003	On request
Caspiycement LLP (dry production)			
Portland cement with mineral additives	CEM II/A-S 42.5 H	GOST 31108-2003	Serial
	CEM II/A-I 32.5 H	GOST 31108-2003	Serial
Portland cement	CEM I 42.5 H	GOST 31108-2003	Serial
Portland sulfate-resistant cement	CEM I 42.5 H CC	GOST 22266-2013	Serial
Portland cement for tamponage	PCT I-CC-100	GOST 1581-96	On request
Shymkentcement JSC (wet and dry production)			
Portland cement with mineral additives	PC 400 D20	GOST 10178-85	Serial
Portland cement of normalized composition	PC 500 D0-H	GOST 10178-85	Serial
Portland cement of normalized composition	PC 400 D0-H	GOST 10178-85	Serial
Portland slag cement	PSC 400	GOST 10178-85	Serial
	PSC 300	GOST 10178-85	Serial
Portland sulfate-resistant cement	PSRC 400 D0	GOST 22266-94	Serial
Portland cement for tamponage	PCT I-G-CC-1	GOST 1581-96	On request
		API Spec10A	On request

2) Steppe Cement LLC (Malaysia) [12], represented in Kazakhstan with a total staff of more than 1000 employees at the plant of Central Asia Cement JSC and its subsidiary Karcement JSC

(Karaganda region). The plant sells cement by the technology of dry method of production. The list of products manufactured by this plant is given in Table 2 below.

Table 2 – Nomenclature of JSC Karcement products [12]

Product name	Brand	Standard	Type
Portland cement of class 42.5 normal hardening	CEM I 42.5 H	GOST 31108-2003	Serial
Portland cement of class 42.5 quick-hardening	CEM I 42.5 B	GOST 31108-2003	Serial
Portland cement with slag from 6% to 20% of class 32.5 normal hardening	CEM II/A-S 32.5 H	GOST 31108-2003	Serial
Portland cement with slag from 21% to 35% of class 32.5 normal hardening	CEM II/B-S 32.5 H	GOST 31108-2003	Serial
Portland cement of grade 400	PC 400 D0	GOST 10178-85	Serial
Portland cement of grade 400 rationed	PC 400 D0 H	GOST 10175-85	Serial
Portland cement of grade 450 rationed (brand name)	PC 450 D0 H	GOST 10178-85	Serial
Portland cement of grade 400 with mineral additives up to 20%	PC 400 D20	GOST 10178-85	Serial
Portland slag cement of grade 400	PSC 400	GOST 10178-85	Serial
Portland slag cement of grade 300	PSC 300	GOST 10178-85	Serial

3) LLP "Standard Cement" (Shymkent) [13] with the number of employees more than 800. Production at the plant is carried out by dry method. The list of products manufactured by the plant is given in Table 2 below.

Table 3 – Nomenclature of Standard Cement LLP products [13]

Product name	Brand	Standard	Type
Portland slag cement of grade 400	PSC 400	GOST 10178-85	Serial
Portland cement of grade 400 with mineral additives up to 20%	PC 400 D20	GOST 10178-85	Serial
Portland cement of grade 400	PC 400 D0	GOST 10178-85	Serial
Portland cement of grade 400 rationed	PC 400 D0 H	GOST 10175-85	Serial
Portland cement	PC 500 D0	GOST 10178-85	Serial

In this study, a comparative analysis of the physical and technical characteristics was carried out only for Portland cement of grade 400 with mineral additives in the amount of 20%.

The determination of grinding fineness was carried out according to [14]. A sieve with a mesh size of 0.08 mm was used for the test (Figure 1). Portland cement samples prepared according to the requirements of [15] were dried at 105-110 °C for 2 h and cooled in a desiccator to prevent absorption of moisture by the material from the air. 50 g of each brand of Portland cement was passed through a sieve using a mechanical sieving device for 5-7 minutes at an accuracy of 0.05 g. This procedure was repeated until no more than 0.05 g of cement passed through the sieve. Control sieving was performed manually on paper for 1 min (Figure 2). The grind fineness of the cements was determined as the residue on the sieve as a percentage of the original sample weight to an accuracy of 0.1%.

Figure 1 – 0.08 mm sieve for determining cement fineness

Figure 2 – Portland cement weighing, passed through 0.08 mm sieve

To determine the compressive strength according to [16], 1.5 kg of sand conforming to [17], 0.5 kg of water and 0.2 kg of binder for each brand of Portland cement were selected. The W/C ratio was 0.4. First, the dry components were mixed for 2 minutes in the bowl of a paddle mixer (Figure 3). Then a well was made in the center of the dry mixture in which water was poured. After half a minute, the mixture was stirred for 1 minute (Figure 4).

Figure 3 – Automatic mixer

Figure 4 – Preparation of the mixture

Next, the mixtures were alternately poured into a cone mold to determine their flow, which should be between 106-115 mm. Otherwise, the W/C ratio should be changed upward or downward. The mixes with the appropriate cone flow (Figure 5) were excessively poured into the 40×40×160 mm beam specimen molds with three specimens for each test period. Compaction of the mixtures placed in the molds was performed on a vibroplatform for 3 minutes. After that, the excess of mixtures was removed flush with the edge of the mold.

Figure 5 – Cone flow

For the first 24 hours, the samples were stored at 90 % relative humidity and 20 ºC, and then they were unmolded and immersed in a bath of water to a depth of 2 cm at the same temperature (Figure 6).

Figure 6 – Steam chamber for thermal-moisture treatment of cement beams

When the storage time was reached, the specimens were removed from the bath and tested on an E 160 N press to determine the bending and compressive strength (Figure 7). The average rate of load build-up during the test was 2.0±0.5 MPa/s.

Figure 7 – Sample of a beam at 28 days of age to determine the bending strength (left) and compression strength (right)

3. Results and Discussion

The results of tests to determine the fineness of Portland cement 400 with 20 % mineral additive is shown in Figure 8 below.

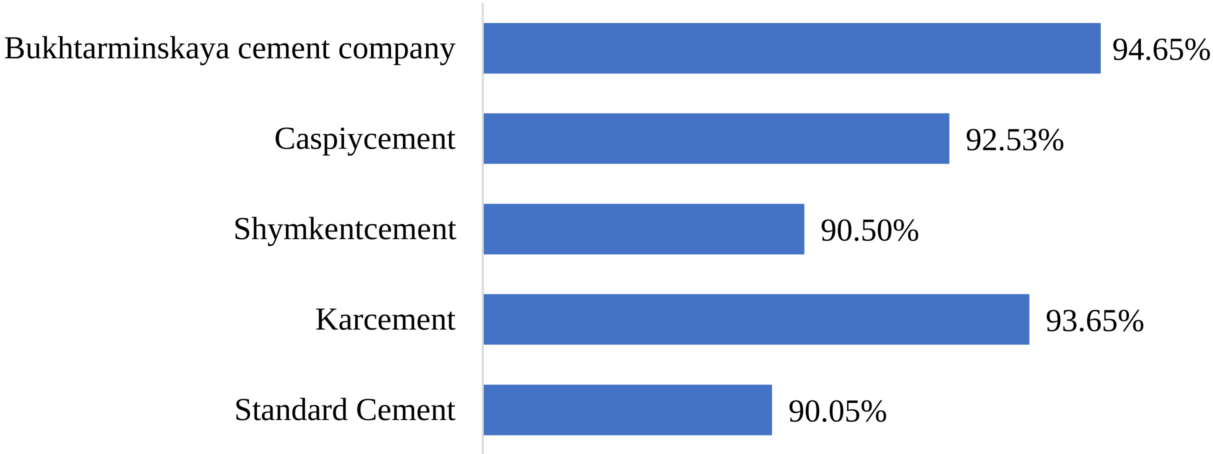

Figure 8 – Grinding fineness

The grinding fineness of the binder used in the design of compositions of cast concrete mixtures affects two factors:

- The higher the grinding fineness, the greater the unit surface area and the more intense the crystallization during hydration, hence the higher the strength characteristics of the final conglomerate;
- The higher the grinding fineness, the higher the water demand of the mixture, hence, the lower the strength characteristics.

The factors have directly opposite effects. However, the difference in grinding fineness of the cements under study has a small gap range. For this reason, a cement with greater grinding fineness is chosen as a binder, which will have little effect on the water demand of the mixture, but, when superplasticizers are used, will affect the strength characteristics in the direction of their increase. This choice is confirmed by the results of tests to determine the strength characteristics of cement at the age of 28 days (Figure 9).

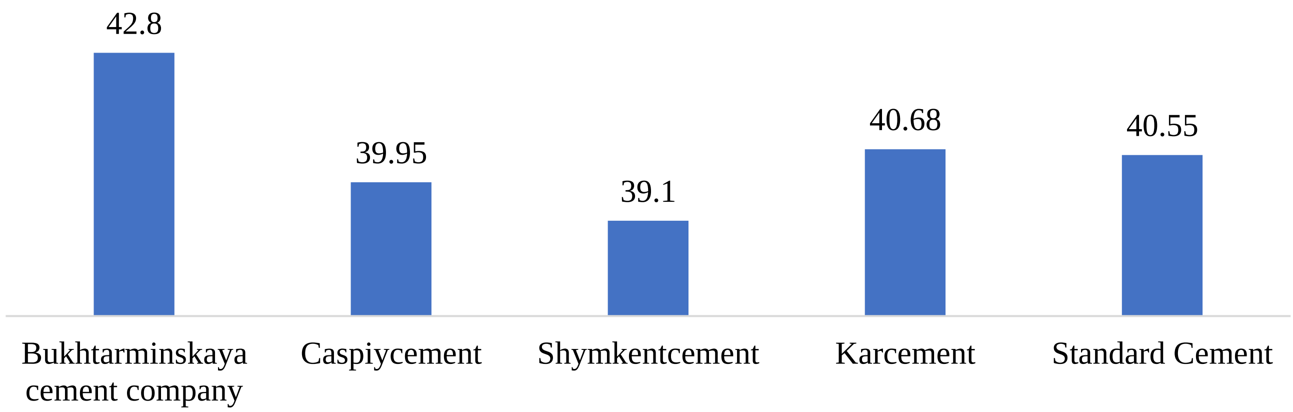

Figure 9 – Compressive strength at 28 days, MPa

According to test results, because of obtaining the highest binder strength indicators the most applicable is PC 400 D20 produced by "Bukhtarminskaya cement company" LLP.

For analysis of cements in order to select as a binder the tests carried out are sufficient. The results of these tests will make it clear which manufacturer's products are more suitable as a raw material component for the design of CMC compositions.

4. Conclusions

Analysis of the nomenclature of the considered suppliers of binders for concrete mixtures revealed a large variety of products offered, produced by both dry and wet method, with and without mineral additives. Based on the characteristics of CMC, Portland cement with mineral additives turned out to be the most optimal binder for its production. A comparative analysis of physical and technical characteristics of Portland cement PC 400 D20 from different local suppliers revealed the following:

1. Grinding fineness of the considered PC 400 D20 varies from 90.05 to 94.65 %;
2. Compressive strength of the considered PC 400 D20 ranges from 39.1 to 42.8 MPa;
3. According to both main parameters the leader is a PC 400 D20, produced by "Bukhtarminskaya cement company" LLP, which can be recommended for use in the production of CMC in the plant LLC "Temirbeton-1" in compliance with the rules and requirements for concretes of this type.

Acknowledgments

This study is based on research work of Associate Professor D.A. Akhmetov "Selection and placement of cast modified concrete of grade M350 with class B25 according to GOST 7473-2010", registered in the database of JSC "NCSTE" under the number № 0122РКИ0119 dated 30.06.2022.

References

1. The Effect of Low-Modulus Plastic Fiber on the Physical and Technical Characteristics of Modified Heavy Concretes Based on Polycarboxylates and Microsilica / D.A. Akhmetov, Y.V. Pukharenko, N.I. Vatin, S.B. Akhazhanov, A.R. Akhmetov, A.Z. Jetpisbayeva, Y.B. Utepov // Materials. — 2022. — Vol. 15, No. 7. — P. 2648. https://doi.org/10.3390/ma15072648
2. Effect of fine fillers from industrial waste and various chemical additives on the placeability of self-compacting concrete / Y. Utepov, D. Akhmetov, I. Akhmatshaeva // Computers and Concrete. — 2020. — Vol. 25, No. 1. — C. 59–65. https://doi.org/10.12989/CAC.2020.25.1.059
3. Experimental study on rheology, strength and durability properties of high strength self-compacting concrete / S.D. Bauchkar, H.S. Chore // Computers and Concrete. — 2018. — Vol. 22, No. 2. — P. 183–196. https://doi.org/10.12989/CAC.2018.22.2.183

4. Effect of modifiers and mineral additives from industrial waste on the quality of aerated concrete products / Y. Sabitov, D. Dyussembinov, D. Bazarbayev // Technobius. — 2021. — Vol. 1, No. 4. — P. 0010. https://doi.org/10.54355/tbus/1.4.2021.0010
5. A review on performance of waste materials in self compacting concrete (scc) / I. Ismail, N. Jamaluddin, S. Shahidan // Jurnal Teknologi. — 2016. — Vol. 78, No. 5. — P. 29-35. https://doi.org/10.11113/jt.v78.8233
6. Determination of Optimal Fibre Reinforcement Parameters for Self-Compacting Concretes / D.A. Akhmetov, A. Aniskin, Ye.B. Utepov, Ye.N. Root, G. Kozina // Tehnicki vjesnik - Technical Gazette. — 2020. — Vol. 27, No. 6. — P. 1982–1989. https://doi.org/10.17559/TV-20200630163212
7. Effect of low-modulus polypropylene fiber on physical and mechanical properties of self-compacting concrete / D. Akhmetov, S. Akhazhanov, A. Jetpisbayeva, Y. Pukharenko, Y. Root, Y. Utepov, A. Akhmetov // Case Studies in Construction Materials. — 2022. — Vol. 16. — P. e00814. https://doi.org/10.1016/j.cscm.2021.e00814
8. Accounting of influence of quality of concrete raw components and of operating conditions on concrete products durability from the perspective of technical regulation / A. Gubskaya, A. Gapotchenko, T. Volovik // Problemy sovremennogo betona i zhelezobetona. — 2019. — No. 11. — P. 108–124. https://doi.org/10.35579/2076-6033-2019-11-08
9. Interstate standard GOST 10178-85 Portland cement and portland blastfurnace slag cement. Specifications [Electronic resource] / MEGANORM // MEGANORM. — [2021]. — Mode of access: https://meganorm.ru/Index2/1/4294853/4294853156.htm
10. Interstate standard GOST 30515-2013 Cements. General specifications [Electronic resource] / MEGANORM // MEGANORM. — [2021]. — Mode of access: https://meganorm.ru/Index2/1/4293771/4293771004.htm
11. Welcome to HeidelbergCement in Kazakhstan [Electronic resource] / HeidelbergCement. — [2022]. — Mode of access: https://kz.heidelbergcement.com/en (accessed date: 29.08.2022).
12. Central Asia Cement [Electronic resource] / CAC. — [2022]. — Mode of access: https://cac.kz/products/ (accessed date: 29.08.2022).
13. Standard Cement [Electronic resource] / SC. — [2022]. — Mode of access: http://standard-cement.com/ (accessed date: 29.08.2022).
14. Interstate standard GOST 310.2-76 Cements. Methods of grinding fineness determination [Electronic resource] / MEGANORM // MEGANORM. — [2021]. — Mode of access: https://meganorm.ru/Index/34/34110.htm
15. Interstate standard GOST 310.1-76 Cement. Test methods. General [Electronic resource] / MEGANORM // MEGANORM. — [2021]. — Mode of access: https://meganorm.ru/Index2/1/4294853/4294853170.htm
16. Interstate standard GOST 310.4-81 Cements. Methods of bending and compression strength determination [Electronic resource] / MEGANORM // MEGANORM. — [2021]. — Mode of access: https://meganorm.ru/Index2/1/4294853/4294853167.htm
17. Interstate standard GOST 6139 Sand for cement testing. Specifications [Electronic resource] / MEGANORM // MEGANORM. — [2021]. — Mode of access: https://meganorm.ru/Index2/1/4293719/4293719479.htm

Information about authors:
Khaidi Khonjo – Master Student, Department of Construction and Building Materials, Satbayev University, Almaty, Kazakhstan, hhonjo0809@gmail.com
Yerzhan Toleuov – Master Student, Department of Construction and Building Materials, Satbayev University, Almaty, Kazakhstan, yer-zhan@mail.ru
Aizere Azbergenova – Master Student, Department of Construction and Building Materials, Satbayev University, Almaty, Kazakhstan, aizeinelkhan@gmail.com
Akkumis Urumbayeva – Master Student, Department of Construction and Building Materials, Satbayev University, Almaty, Kazakhstan, urumbayevaakkumis@gmail.com

Author Contributions:
Khaidi Khonjo – concept, resources, drafting, testing.
Yerzhan Toleuov – methodology, modeling, analysis, funding acquisition.
Aizere Azbergenova – data collection, visualization.
Akkumis Urumbayeva – interpretation, editing.

Received: 02.09.2022
Revised: 11.09.2022
Accepted: 11.09.2022
Published: 11.09.2022

Technobius, 2022, 2(3), 0023, DOI: https://doi.org/10.54355/tbus/2.3.2022.0023

Technobius

https://technobius.kz/

e-ISSN

2789-7338

Article

Research of foam concrete components in the regional production conditions of Nur-Sultan

Rauan Lukpanov[1], Duman Dyussembinov[1], Aliya Altynbekova[1,2,*], Zhibek Zhantlesova[1,2]

[1]Solid Research Group, LLP, Nur-Sultan, Kazakhstan
[2]L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan
*Correspondence: kleo-14@mail.ru

Abstract. The article presents results of the effect of one component of the modified additive (post alcohol bard) on the change in the setting time of the cement mixture. The work shows a method for determining the setting time, the selection of optimal composition of samples, which will accelerate the setting time (beginning and end). Performed a comparative study of cements from different manufacturers, as well as the effect of one component of the modified additive (post-alcohol bard) on the setting time. The research allows to determine the effect of plasticizing additive on the properties of foam concrete during their production. It is established that the introduction of the additive can reduce the time of the beginning and the end of setting, the introduction of additive (post-alcohol bard) in optimal quantities will accelerate the process of making foam concrete products. Obtained results of setting time in the samples using the additive led to the best results. In general according to the results of studies it can be concluded that the additive promotes the growth rate of plastic strength and setting of foam concrete mixture, accelerates the hardening of foam concrete and can reduce its shrinkage during hardening. Consequently, the additive is one of the most effective additives to accelerate setting and allows mortars to fully set in the shortest time intervals.
Keywords: modified additive, post-alcohol bard, setting time, foam concrete, plasticizer.

1. Introduction

Due to the rapid development of construction production has appeared many building materials, one of which is foam concrete. Foam concrete has various physical and mechanical characteristics, ease of production, low cost, a relatively small mass of blocks. Because of this, it became widely used in construction.

The basis of modern concrete technology is the creation of high-quality artificial stone, characterized by high dispersion, a small imperfection and structure stability. Improvement in quality of concrete compositions can be achieved both by use of chemical additives, and when using local components to create a new generation of concrete, which is a highly relevant objective of concrete technology. A new generation of concrete are high-tech, high-quality, multi-concrete mixtures and compositions with additives that preserve the required properties at a service in all operating conditions. Growing multicomponent concretes are due to significant systemic effects, what enables to manage the structure formation at all stages of the technology, ensuring receipt of composites of «directed» quality, composition, structure and properties [1-7].

The use of complex additives is now generally recognized as an effective way to improve the performance of cement concrete. In most cases, additives are now a mandatory part of the concrete mixture. Analysis of scientific and technical literature shows that additives increasing the rate of setting and hardening of cement are in demand, so the interest in the development of new, competitively capable accelerating additives is not weakening [8].

A wide range of domestic and imported chemical additives makes it difficult to make a choice. Concrete manufacturers seek to improve its properties by modification, while reducing the consumption of cement, reduce energy costs in the production of reinforced concrete, and minimize the cost of additives under stable terms of their quality. It is quite a challenging task that can be solved using a variety of waste and coproducts of many industries as mineral and chemical modifiers of concrete [9-13].

The main direction of intensification of technological processes in modern construction is the widespread use of various additives to cement-containing systems, among which plasticizers thinners are of great importance, allowing to significantly reducing the water consumption of concrete mixtures without reducing mobility. As plasticizers of cement mixtures surface-active substances are widely used either specially synthesized or by-products of various industries, many of which are environmentally unsafe [14].

Setting of concrete is identified as the transition of fresh concrete from liquid phase to solid phase. It is important to identify this phase change to plan transporting and placing of concrete [15].

In order to improve the technological properties, special additives are introduced into mortar mixtures, surface-active substances that have a plasticizing (post-alcohol bard) effect.

The aim of the study is to evaluate the setting time of cement mortars of different manufacturers for its further use in the production of foam concrete, as well as the effect of one component of the modified additive (post-alcohol bard) on the change in the setting time. The problem of utilization of post-alcohol bard formed during the operation of factories producing alcohol is still an urgent problem. Utilization (recycling) of post-alcohol bard and other undesirable impurities of production in a biotechnological way will ensure environmental safety of industrial enterprises producing alcohol (distillery and hydrolysis) by eliminating the discharge of bard into the environment.

In order to achieve the goal, the following tasks were solved:

1. Selection of the optimal composition of samples of compared cement mortars;
2. Laboratory studies of the setting time of samples with and without the addition of the component;
3. Comparative analysis of test results of specimens with and without component addition;
4. Selection of a cement manufacturer with optimal results of setting times, the most favorable for the production of foam concrete.

Comparisons of the results of laboratory tests carried out for the compositions:

Type-1: Reference sample without additives (Zhambyl-Cement);

Type-2: Sample with additive (3% post-alcohol bard) by weight of the reference cement (Type-1);

Type-3: Reference sample without additives (Central Asia Cement);

Type-4: Sample with additive (3% post-alcohol bard) by weight of reference cement (Type-3);

Type-5: Reference sample without additives (Kokshe-Cement);

Type-4: Sample with additive (3% post-alcohol bard) by weight of reference cement (Type-5).

2. Methods

Raw materials produced on an industrial scale were mainly used in laboratory studies. Their main characteristics as defined by the current standards are given below.

Portland cement M400 type CEM I 42.5 N (Karaganda (Central Asia Cement), Zhambyl-Cement and Kokshe-Cement) cement factory, which meets the requirements of GOST 31108-2016 [16].

The fine aggregate was quartz sand from quarries in Akmola region. Modulus of grain size – 2.7, meets the requirements of GOST 8736-2014 [17].

Alcohol production waste was used as a modifying additive (post-alcohol bard, produced according to TU 5870-002-14153664-04 [18], in an amount of 3% by weight of cement).

Tap water as mixing water for concrete mixture, corresponding to the requirements of GOST 23732-2011 [19].

Consumption of raw materials of cement mortar samples (required for measuring the setting time) are presented in Table 1. Mineralogical and chemical composition of cements CEM I 42.5 N from different manufacturers are presented in Tables 2 and 3.

Table 1 – Composition of cement mortar types compared

No	Type	w/c ratio	Cement	Post-alcohol bard	NaOH	Water
1	Type-1, 3, 5 Reference sample without additives	0.3	350	-	-	105
2	Type-2, 4, 6 Sample with additive (3% post-alcohol bard)	0.3	350	10.5	0.525	93.975

Table 2 – Mineralogical composition of cements CEM I 42.5 N

No	Type	C_3S	C_2S	C_3A	C_3AF
1	Zhambyl-Cement	57.27	14.87	8.28	14.28
2	Central Asia Cement	47.92	19.09	8.65	13.6
3	Kokshe-Cement	47.92	19.09	8.65	13.6

Table 3 – Chemical composition of cements CEM I 42.5 N

No	Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O_3	K_2O
1	Zhambyl-Cement	24.81	6.06	2.81	64.49	2.97	3.12	0.23	0.87
2	Central Asia Cement	27.16	5.92	3.03	63.67	2.75	3.03	0.26	1.01
3	Kokshe-Cement	27.52	5.79	3.33	59.10	2.36	3.01	0.28	1.02

Figure 1 – Determination of the setting time of the dough of standard consistency (beginning and end of setting)

Effect of additives on the time of setting of the cement system (as shown in Figure 1) was determined in accordance with the requirements of GOST 310.3-76 [20].

3. Results and Discussion

An important indicator of construction and technical cements is the setting time, because this indicator depends on how economically water is used as one of the important resources in construction and how long it takes to build.

Setting is the process by which a relatively mobile mixture of cement and water gradually thickens and acquires an initial strength such that its mechanical processing becomes practically difficult or even impossible. Therefore, binders, including cements, should be characterized by such a setting time, which makes it possible to prepare mortar and concrete mixes and use them in business. A distinction is made between the beginning and the end of the setting time of a particular binder. Conventionally, in accordance with the standards of these terms are determined on the test of normal density at 20°C by the depth of immersion in it the needle Vica. According to GOST 10178-85 [21] beginning of the setting of the dough, this binder should come not earlier than 45 minutes and the end of setting time not later than 10 hours, counting from the moment of mixing the cement with water.

In the experiments, we used three types of cement, which are the main Portland cement of mass production in the Republic of Kazakhstan, which have different mineralogical and material properties (Table 4). The results in the table show that the additive in sufficient quantities leads to changes in setting time compared with no additive composition, but within the standards established by GOST 10178-85 [21].

Table 4 – Setting times of Portland cements of different mineralogical compositions with additives

Type	Additive, % of binder weight	Cement	w/c ratio	Setting time, h-min beginning	Setting time, h-min end
Type-1	without additive	Zhambyl-Cement	0.3	3:20	6:50
Type-2	post-alcohol bard 3%	Zhambyl-Cement	0.3	2:10	5:20
Type-3	without additive	Central Asia Cement	0.3	2:45	6:10
Type-4	post-alcohol bard 3%	Central Asia Cement	0.3	1:30	4:10
Type-5	without additive	Kokshe-Cement	0.3	3:00	6:40
Type-6	post-alcohol bard 3%	Kokshe-Cement	0.3	1:55	4:40

Table 4 shows that all three cements under study had setting times that meet the requirements of GOST 10178-85 [21]. However, Zhambyl-Cement has a longer setting time than Central Asia Cement and Kokshe-Cement. The additive accelerated the beginning and the end of setting time of cements.

The values in the diagram (Figure 2) show how Portland cements will behave with the additive during mixing. Plasticizing additive decreased water consumption by 1.5 % for Central Asia Cement, by 1.2 % for Kokshe-Cement and by 0.5 % for Zhambyl-Cement when added in 3% of cement mass. In connection with this we can conclude that a certain reduction of water for kneading the mixture (by 20-25%) to obtain the dough of normal density leads to the features of hydrophobic and plasticizing additives.

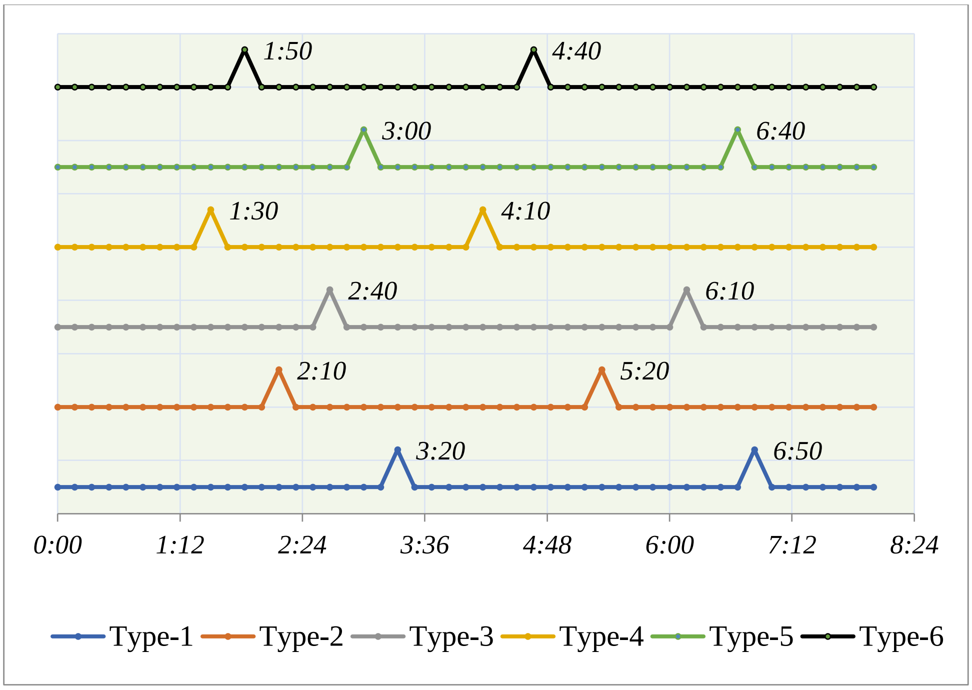

Figure 2 – Setting times of cements of different mineralogical compositions with an additive

According to the results of the study, determined the time of setting of the compositions for:

Type-1. The beginning of setting of the cement mixture without additive is 3 h 20 min, and the end of setting is 6 h 50 min.

Type-2. When adding 3% additive (post-alcohol bard) in the cement mixture, the beginning of setting time is 2 hours 10 minutes and the end of setting time of 5 hours 20 minutes, respectively.

Type-3. The beginning of setting of the cement mixture without the additive is 2 h 40 min and the end of setting 6h 10 min.

Type-4. When adding 3% additive (post-alcohol bard) in the cement mixture, the beginning of setting time is 1 hour 30 minutes and the end of setting time of 4h 10 minutes, respectively.

Type-5. The beginning of setting of the cement mixture without additive is 3 h 00 min and the end of setting is 6 h 40 min.

Type-6. When adding 3% additive (post-alcohol bard) in the cement mixture, the beginning of setting time is 1 hour 50 minutes and the end of setting time of 4h 40 minutes, respectively.

When comparing the time of setting of these cements made with mortars with and without additives, it was found that with the introduction of additives the difference is even more noticeable. Thus, the difference in the beginning of setting time is 2 hours 10 minutes and the end of setting time is 5 hours 20 minutes for Zhambyl-Cement, the beginning of 1 hour 30 minutes and the end of 4 hours 10 minutes for Central Asia Cement and the beginning of 1 hour 50 minutes and the end of 4 hours 40 minutes for Kokshe-Cement. The results convincingly prove the effectiveness of the proposed additive consisting of post-alcohol bard. The analysis of experimental data relating to the effect on the time of setting shows that the additive is more effective in 3% dosage. In general, according to the results of these studies it can be concluded that the use of the additive increases the growth rate of plastic strength and setting of foam concrete mixture, accelerates the hardening of foam concrete and is able to reduce its shrinkage during curing.

4. Conclusions

The following conclusions can be made on the basis of the experimental studies:

1. The use of cements from different manufacturers in the production of foam concrete makes its own adjustments in the properties of the cellular concrete mixture at the stage of forming and maturation of the mass.

2. Mineralogical composition of cement from different manufacturers affects the strength of concrete. Among the materials studied cement Zhambyl-Cement has the least, and Central Asia Cement and Kokshe-Cement - the greatest influence on the time of setting. Consequently, Central Asia Cement showed the best results of setting time in the samples using the additive (Type-4 beginning 1h 30 min, end setting 4h 10 min) for its further use in the production of foam concrete.

3. In accordance with the results obtained for the setting time in the samples, it can be said that the introduction of an additive with a volume of 3% leads to the maximum decrease in the necessary moisture for normal density in all cements.

4. The additive proved to be one of the most effective additives for accelerating setting, the introduction of this additive in an amount of 3% by mass allowed the mortars to fully set in the shortest time intervals. If an additive in the amount of 3% is added to the cement batter, the final setting will be faster in all cases.

Acknowledgments

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant № AP13068424).

References

1. How to transform the old generation concrete in high-performance concretes of new generation / V.I. Kalashnikov // Concrete and reinforced concrete. — 2012. — Vol. 1, No. 1. — P. 82–89.
2. Microstructure and mechanical properties of polymer-modified mortars / S. Marceau, F. Lespinasse, J. Bellanger, C. Mallet // European Journal of Environmental and Civil Engineering. — 2012. — Vol. 16, No. 5. — P. 571–581. https://doi.org/10.1080/19648189.2012.675148
3. Polymer-modified concrete with improved flexural toughness and mechanism analysis / C. Qingyu, S. Wei, G. Liping, Z. Guorong // Journal of Wuhan University of Technology-Materials Science Edition. . — 2012. — Vol. 27, No. 1. — P. 597–601. https://doi.org/10.1007/s11595-012-0512-5
4. Waterproof performance of concrete: A critical review on implemented approaches / N.Z. Muhammad, A. Keyvanfar, M.Z. Abd. Majid, A. Shafaghat, J. Mirza // Construction and Building Materials. — 2015. — Vol. 101, No. 1. — P. 80–90. https://doi.org/10.1016/j.conbuildmat.2015.10.048
5. Chemical admixtures-Chemistry, applications and their impact on concrete microstructure and durability / J. Plank, E. Sakai, C.W. Miao, C. Yu, J.X. Hong // Cement and Concrete Research. — 2015. — Vol. 78, No. 1. — P. 81–99. https://doi.org/10.1016/j.cemconres.2015.05.016
6. Mechanical and dynamic properties of high strength concrete modified with lightweight aggregates presaturated polymer emulsion / Y. Tian, S. Shuaifeng, H. Shuguang // Construction and Building Materials. — 2015. — Vol. 93, No. 1. — P. 1151–1156. https://doi.org/10.1016/j.conbuildmat.2015.05.015
7. Development of multi-mineral binders / Yu.D. Chistov, A.S. Tarasov // Russian Chemical Journal. — 2003. — Vol. 4, No. 1. — P. 12–17.
8. Polymer concrete based on epoxy and polyester resins using asbestos-frictional materials waste / S.A. Strulev, V.P. Yartsev // Academy. Architecture and Construction. — 2011. — Vol. 3, No. 1. — P. 109–111.
9. Complex additive for cement binder / Shirshaeva D.V., Ustyugov A.S. // Selected papers of the 65th Jubilee University Scientific and Technical Conference of Students and Young Scientists. — Tomsk. 2019. — P. 878–879.
10. Effects of ultrafine fly ash on the properties of high-strength concrete / F. Jingjing, L. Shuhua, W. Zhigang // Journal of Thermal Analysis and Calorimetry. — 2015. — Vol. 121, No. 1. — P. 1213–1223. https://doi.org/10.1007/s10973-015-4567-3
11. Modified Cement-Based Mortars: Crack Initiation and Volume Changes / I. Havlikova, V. Bilek, L. Topolar, H. Simonova, P. Schmid, Z. Kersner // Materials in Technology. — 2015. — Vol. 49, No. 4. — P. 557–561. https://doi.org/10.17222/mit.2014.179
12. The influence of penetrating special polymer sulfur binder, Polymerized sulfur applied as the industrial waste material on concrete watertightness / M. Ksiazek // Composites Part B, Engineering. — 2014. — Vol. 62, No. 1. — P. 137–142. https://doi.org/10.1016/j.compositesb.2014.02.027
13. Mix design process of polyester polymer mortars modified with recycled GFRP waste materials / M.C.S. Ribeiro, A. Fiuza, A.C.M. Castro, F.G. Silva, M.L. Dinis, J.P. Meixedo, M.R. Alvim // Composite Structures. — 2013. — Vol. 105, No. 1. — P. 300–310. https://doi.org/10.1016/j.compstruct.2013.05.023
14. Prospective plasticizing additive for cement systems from post-alcohol bard / V. D. Cherkasov, V. I. Buzulukov, A. I. Emelyanov // Bulletin of the Volga regional branch of the Russian Academy of Architecture and Building Sciences. — 2014. — Vol. 17, No. 1. — P. 264–266.

15. Evaluation of initial setting time of fresh concrete / R.C.C. Piyasena, P.A.T.S. Premerathne, B.T.D. Perera, S.M.A. Nanayakkara // Proceedings of National engineering conference. — 2013. — P. 47–52.
16. GOST 31108-2016 General Construction Cements. — 2016.
17. GOST 8736-2014 Sand for construction works. — 2014.
18. TU 5870-002-14153664-04 Complex additives for concrete and mortars. — 2005.
19. GOST 23732-2011 Water for concretes and mortars. — 2011.
20. GOST 310.3-76 Cements. Methods for determining the normal density, setting time and volume change uniformity. — 1976.
21. GOST 10178-85 Portland and slag-portland cement. — 1985.

Information about authors:

Rauan Lukpanov – PhD, Professor, Scientific Supervisor, Solid Research Group, LLP, Astana, Kazakhstan, rauan_82@mail.ru
Duman Dyussembinov – Candidate of Technical Sciences, Associate Professor, Senior Researcher, Solid Research Group, LLP, Astana, Kazakhstan, dusembinov@mail.ru
Aliya Altynbekova – Researcher, Solid Research Group, LLP, Astana, Kazakhstan; PhD Student, Department of Technology of Industrial and Civil Construction, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, kleo-14@mail.ru
Zhibek Zhantlesova – Junior Researcher, Solid Research Group, LLP, Astana, Kazakhstan; PhD Student, Department of Technology of Industrial and Civil Construction, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, zhibek81@mail.ru

Author Contributions:

Rauan Lukpanov – concept, methodology, visualization, funding acquisition.
Duman Dyussembinov – analysis, interpretation, resources.
Aliya Altynbekova – data collection, testing.
Zhibek Zhantlesova – editing, modeling, drafting.

Received: 05.09.2022
Revised: 13.09.2022
Accepted: 19.09.2022
Published: 19.09.2022

Technobius, 2022, 2(3), 0024, DOI: https://doi.org/10.54355/tbus/2.3.2022.0024

Technobius

https://technobius.kz/

e-ISSN 2789-7338

Article

Potential applicability of tailings as fine aggregate for concrete paving slabs

Zulfiya Aubakirova[1,*], Aldiyar Temirbekov[1], Monika Kulisz[2], Gulnaz Zhairbaeva[1]

[1]School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan
[2]Department of Management, Lublin University of Technology, Lublin, Poland
*Correspondence: aubakirova.zulfiya@mail.ru

Abstract. Statistics of recent years shows an annual increase in the volume of technogenic waste (in particular "tailings") of mining and metallurgical enterprises of Kazakhstan by about 1.5 billion tons, which at the current time is already about 4.7 billion that entails certain environmental and economic consequences. This article proposes the potential use of the tailings of the enterprises as a fine aggregate to partially replace the consumption of cement in the concrete mixture for the manufacture of paving slabs. Carbonate tailings of Kazzinc LLP enterprise were used. To determine the optimum composition of concrete mix with the use of tailings were made control and 4 experimental compositions with the replacement of part of the cement waste in the amount of 5, 10, 15, 20% respectively. Samples of concrete mixtures were tested for compressive strength, flexural tensile strength, abrasion, frost resistance, and resistance to wetting and drying. According to the test results, it was found that as the concentration of tailings increases, the physical-mechanical and operational indicators of the concrete mixture and concrete for the manufacture of paving slabs improve.
Keywords: technogenic waste, tailings, aggregates, concrete, paving slabs.

1. Introduction

The application in processing of technogenic raw materials in warehouses, waste mines, mining and processing plants (MPPs) is a secondary resource for use in modern global production, since it ensures the release of occupied tailings ponds, warehouses, land and vehicles from toxic technogenic waste. Thus, environmental pollution is reduced, the ecological situation in the area of mining enterprises' management significantly improves, and the degraded ecosystems of entire regions are restored. This trend is observed in most industrially developed countries: the USA, Italy, Canada, Great Britain, Poland, as well as in South Africa, Spain, Portugal, and other countries. For example, in the USA aluminum accounts for 20 % of technogenic waste, iron – 33 %, lead and zinc – 50 %, copper – 44 %, while in Kazakhstan and abroad these figures do not exceed 15%. Thus, the share of building sector of Kazakhstan in use of technogenic waste does not exceed 1,5 - 2 % [1].

Almost half of the total mass of ore during enrichment forms a special type of technogenic waste - "tailings", which are quartz-iron sand consisting of particles of 0.14-0.63 mm. The presence of a large amount of iron compounds in the composition of these wastes causes their higher density than the natural sand [2].

Different chemical composition, physical and chemical parameters and properties of the technogenic waste formed during mining and concentration of ores determine the variety of construction materials obtained on their basis. The basic direction of recycling of this group of wastes is the production of non-metallic materials, first of all, aggregates of concrete and mortars, road-building materials, cobble-stone, etc. The cost of aggregates from technogenic waste, including tailings, is usually lower than that of natural materials. For example, in the conditions of the East Kazakhstan oblast the fractionated wastes of ore dressing plants are 6-10 times cheaper than sand. The use of technogenic wastes reduces the cost of concrete products by 10-15 %.

Mineral extraction all over the world is characterized by an increase in the volume and area of mining operations due to the dynamic development of the needs of human society, which causes significant harm to the environment. For example, the total amount of technogenic waste from mining and metallurgical enterprises in Kazakhstan increases by approximately 1.5 billion tons per year. At the current moment, the total reserves of enrichment production wastes already amount to 4.7 billion tons and occupy an area of 164.14 square kilometers. The waste from enrichment plants is a finely ground product with the grain size of 0.074 mm in the volume of 40-80 % and 0.15 mm in the volume of 10-15%. The chemical composition is mainly represented by silica (67-72 %), alumina (11-12 %), calcium oxide (2.6-4.5 %) [3].

Continuous growth of the volume of waste production, raises the question of the need to find effective ways of their practical application. In this regard, the authors of this study proposed the possibility of replacing part of the cement introduced into the concrete mixture by tailings wastes from 5 to 20 %. The purpose of the experiment was to obtain a concrete mixture for the production of paving slabs. To achieve the goal, tests were carried out to determine the optimal composition of the concrete mixture, satisfying the requirements for compressive strength, bending tension, abrasion, frost resistance, and resistance to wetting and drying.

2. Methods

In order to obtain the optimal composition of the concrete mixture were made control and experimental samples (Table 1).

Table 1 – Test sample compositions

Samples	Percentage of cement replacement, %	Material consumption per 1 m^3 of mixture			
		Cement, kg	Sand, kg	Tailings, kg	Water, l
Reference:	0	594.4	1634	-	171.2
Experimental:					
No. 1	5	564.7	1634	29.7	171.2
No. 2	10	535.0	1634	59.4	171.2
No. 3	15	505.2	1634	89.2	171.2
No. 4	20	475.6	1634	118.8	171.2

To select the optimal composition of the concrete mixture in the experiment was used:

- Cement grade M400 D0 [4] produced by UCG Company (Almaty), in Ust-Kamenogorsk;
- Quartz sand with particle size modulus of 2.5 microns according to [5] and [6] produced by LLP "Polypak S" (Karaganda);
- Water for concrete mixture mixing according to [7].

The procedure for determining the properties of cement was:

- Determination of cement fineness according to [8] and [9];
- Determination of normal density and setting time of cement dough [9].

Procedure for determining the properties of sand:

- Determination of the coarseness modulus of sand according to [10];
- Determination of the content of dust and clay particles in the sand according to [10];
- Determination of the true density of sand according to [10];
- Determination of bulk density of sand according to [10];
- Determination of hollowness according to [10].

For the purposes of the experiment, the tailings of Kazzinc LLP's mining and processing plants were used. The composition of enrichment tails was determined by quantitative elemental analysis of the studied material using mass spectrometry and atomic emission spectrometry. The analysis revealed that the "tailings" are of carbonate nature and are a finely ground product, which does not require additional grinding before use. The granulometric composition of the waste is as follows: grains smaller than 85 microns are 25-30 %, 85-200 microns – 55-65 % microns, and larger than 200 microns – 10-15 %.

The main minerals in the tailings are: dolomite 50-60 %; limestone 10-15 %; barite 10-20 %; clay matter 5-8 %; ore minerals 2-3 % [11]. Analysis for radiation pungent odor was also conducted. Radiation pungent odor is moderate, i.e., safe. Chemical composition of enrichment tails used during the experiment is shown in Table 2.

Table 2 – Chemical composition of tailings

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$BaSO_4$	FeS_2	PbS	$PbSO_4$	$PbCO_3$	Calcination losses
Content, wt. %	4.2	0.9	2.5	26.8	14.5	12.7	4.8	0.14	0.03	0.09	33.34

Tests of tailings for radionuclides were carried out in accordance with [12]. The results of these tests are given in Table 3 below.

Table 3 – Results of waste testing for radionuclides

The indicator to be determined	Unit	Value of the characteristic		
		according to [12]	during testing	errors
Radionuclides:				
thorium-212	Bq/kg	< 370	9.4	± 2.64
cesium-137	Bq/kg	< 370	9.2	± 2.76
strontium-90	Bq/kg	< 370	9.7	± 2.61

Samples from the concrete mixture for the experiment were prepared in the following sequence:

- All components of the mixture were weighed;
- Dosed sand, Portland cement and tailings were loaded into the mixer, which were then stirred for 2 minutes, then incubated for 50 minutes (Figure 1);
- Indicators of dry mixture were determined according to [8], the values of which are: bulk density 1100 kg/m^3; true density 3155 kg/m^3; normal density 25.5 %; specific surface 2500 cm^2/g; porosity 58 %;
- The mixture was mixed with the addition of water;
- From the resulting concrete mixture samples were made, which are subjected to heat and moisture treatment at 80-85 º C and then tested for compressive and flexural strength [13], abrasion [14], frost resistance [15] and resistance to wetting-drying [16].

To determine the compressive strength, specimens-cubes with dimensions of 15×15×15 cm were prepared, and for tensile strength, prism specimens with dimensions of 10×10×40 cm were prepared.

Figure 1 – Preparation of concrete samples for the experiment

3. Results and Discussion

The properties of the obtained samples of concrete mixture for the manufacture of paving tiles according to the test results are presented in Table 4.

Table 4 – Results of an experimental study of the properties of concretes

Samples	Portland cement replacement rate, %	Physical and mechanical indicators				
		Compressive strength, MPa	Tensile strength at bending, MPa	Abrasion resistance, g/cm^2	Frost resistance, cycles	Wetting-drying resistance, cycles
Reference	0	25.2	3.2	0.282	25	520
No. 1	5	29.3	3.7	0.281	35	650
No. 2	10	32.2	3.9	0.276	50	680
No. 3	15	34.5	4.2	0.275	55	690
No. 4	20	39.4	4.3	0.273	65	720

The results of tests on the compressive strength of samples showed that the highest index was obtained for sample No. 4 (Figure 2), this is the sample with the highest percentage of replacement of Portland cement with waste (20 %). It is evident that the compressive strength increases as the percentage of replacement increases. This appears to be due to an increase in the proportion of ore minerals, catalytic and modifying elements contained in the tailings.

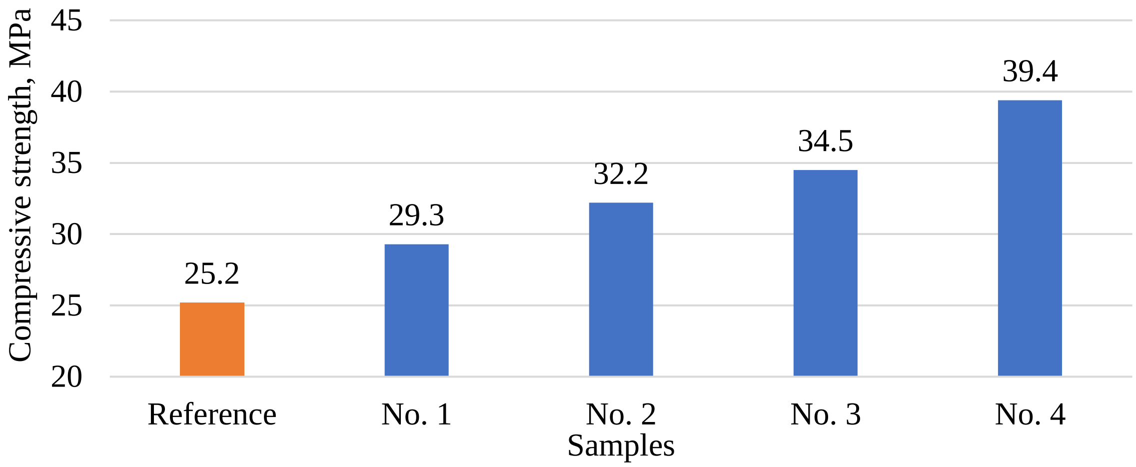

Figure 2 – Compressive strength test results of the specimens

The highest bending tensile strength value was also obtained for specimen No. 4 (Figure 3).

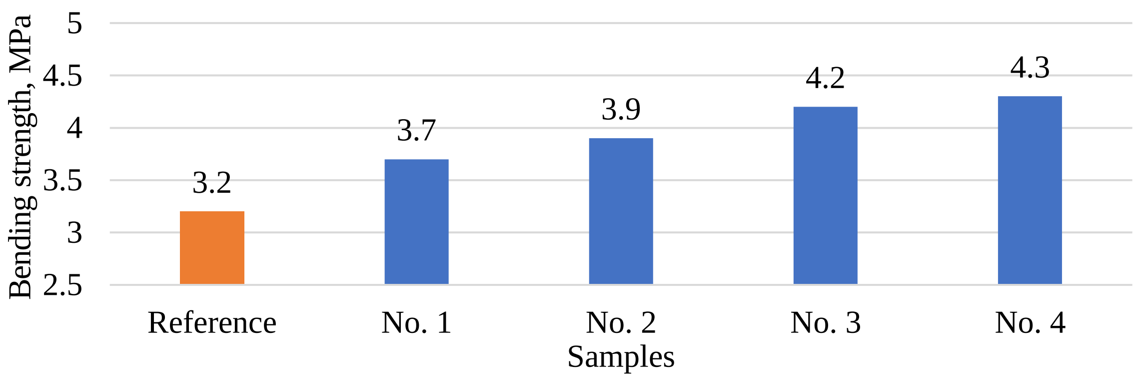

Figure 3 – Results of bending strength test of specimens

Figure 3 shows that the flexural strength class of the introduction of tailings to replace part of the cement increases as the proportion of replacement increases.

The obtained data confirm the suggested assumption that the inclusion of dolomite tailings at lower content of Portland cement and, consequently, clinker provides the maximum convergence of deformation characteristics of cement-slag stone and slag aggregate in concrete, as well as the highest values of their cohesion (adhesion) [17].

In particular, this is due to the formation in the contact zone of crystallization structures, firmly fused with the slag and cement stone in their physical and chemical interaction [18].

Obviously, the role of the addition of dolomites and calcite in the system is to enhance hydration of fine particles of tailings and the interaction of cement with it. All this causes an increase in the deformation-structural homogeneity of the concrete mixture, and, consequently, its durability, as well as an increase in the tensile strength of the sample at bending [19].

Abrasion tests of the samples showed that the abrasion of the material decreases as the proportion of replacement of Portland cement with waste (Figure 4).

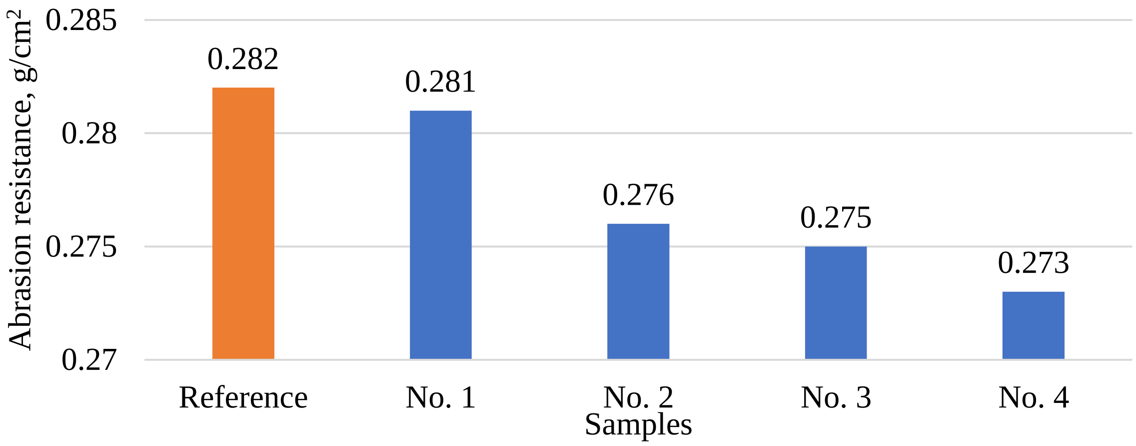

Figure 4 – Results of abrasion tests on samples

This means that the introduction of enrichment tails insignificantly reduces the abrasion resistance of the material compared to the indicator of the control sample.

Regarding the index of frost resistance, we can conclude that the experimental samples have a much higher index than the control sample (Figure 5).

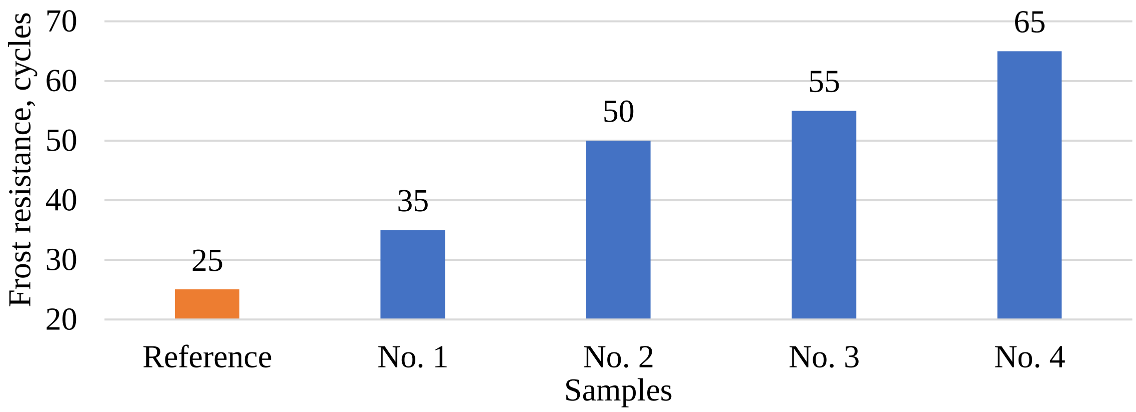

Figure 5 – Test results of samples for frost resistance

Figure 5 shows that the inclusion of polymetallic ore tailings in the composition of concrete instead of part of the cement allows to obtain material withstanding from 35 to 65 cycles.

The study of durability of samples during moistening-drying showed that the experimental samples durability index is much higher than that of the control sample, and the number of cycles increases with increasing the share of technogenic waste – polymetallic ore tailings in the experimental samples (Figure 6).

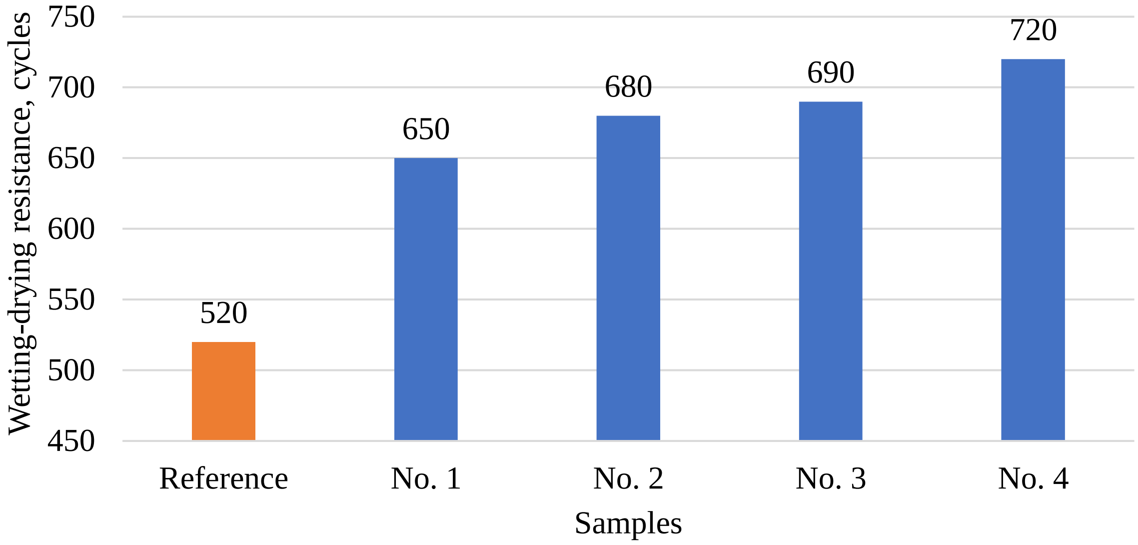

Figure 6 – Resistance test results for wetting and drying

Thus, tests of experimental samples for compressive strength, bending tensile strength, abrasion, frost resistance and resistance to wetting-drying were carried out.

Analysis of the experimental results showed that the introduction of enrichment tails instead of part of the cement allows you to get materials with improved physical and mechanical properties.

The results obtained are consistent with the available empirical data on the problem of research.

In particular, in [20] it is shown that the volume of formed crystalline calcite depends on the calcium released during slag dispersion. In the development of cements with given properties, hydrate compounds or anhydrous minerals morphologically homogeneous with slag-alkali stone hardening products serve as crusts for crystallization of secondary phases.

In [21] it is shown that drying cracks in the hydrated amorphous phase when the aqueous soda solution is removed are not typical for the modified slag-alkali stone because the reaction of interaction of slag with aqueous soda solution proceeds more completely with introduction of additives. The fine-grained structure of the artificial stone, which provides damping of internal stresses during structure formation and higher resistance to external stresses during operation, probably, among other factors, predetermines higher strength of cements in comparison with unadded ones.

It was shown in [22-23] that limestone can be used as a mineral additive in the clinker of Portland cement. In Portland cement with carbonate fillers the active structure-forming role of fine limestone particles in the forming cement stone is primarily determined by chemical interaction of calcium and magnesium carbonates with hydration products of aluminous clinker phases.

From the above empirical data, it follows that the joint grinding of Portland cement with the addition of carbonate fillers will allow its active use in the composite cement, and additives from carbonate rocks can be used as a filler. Mineral additives of metallurgical technogenic raw materials used in the production of mixed cements and their participation in the formation of artificial cement stone is based on pozzolanic nature of hardening, appearing through acid-base interaction in aqueous solution of structural elements of Portland cement clinker and additive [24].

It should be noted that the above studies emphasize that the receipt of mixtures based on the tailings of polymetallic enterprises allows to obtain products with high physical, technical and operational characteristics.

Thus, during the experiment concrete samples were made with the introduction of various proportions of tailings (from 5 to 20 %). Five samples (one control and four experimental) under laboratory conditions were tested for compressive strength, bending tensile strength, abrasion, frost resistance and resistance to wetting-drying.

The best indices were obtained for sample No. 4, as the best indices of frost resistance, abrasion resistance, resistance to wetting and drying, bending strength and compressive strength were obtained for this composition.

4. Conclusions

For the purposes of the experiment were made one control and 4 experimental compositions (with replacement of part of the cement waste 5, 10, 15, 20%) of the concrete mixture. The control sample consisted of Portland cement and silica sand and was mixed with water.

During the experiment, samples were tested for: compressive strength; tensile strength at bending; abrasion; frost resistance; resistance when wetting-drying.

The best indicators were obtained for specimen No. 4, as the best indicators of frost resistance, abrasion resistance, resistance to wetting and drying, bending strength and compressive strength were obtained for this composition.

Experimental study showed that as the weight of the added enrichment tails in the sand-concrete mixture increases, the physical-mechanical and operational indicators of the mixture samples for sidewalk slabs are improved.

Thus, experimentally proved the possibility of using tailings as a substitute for a certain amount of cement in the manufacture of small concrete products (paving slabs) with high performance and physical-mechanical characteristics.

It has been proved that obtaining concrete mixtures with the addition of tailings of polymetallic enterprises allows obtaining products with high physical-technical and operational characteristics.

References

1. Razrabotka tehnologij izgotovleniya stenovyh blokov s primeneniem mineralnyh dobavok na osnove tehnogennogo syrya predpriyatij g. Ust-Kamenogorska / V.A. Magerova. — Ust-Kamenogorsk, Kazakhstan: 2011. — 20 p.
2. Tehnogennye mestorozhdeniya: ot ispolzovaniya imeyushihsya – k sozdaniyu bolee sovershennyh / V.D. Evtekhov // Geology and Mineralogy Bulletin of Kryvyi Rih National University. — Vol. 9, No. 1. — P. 19–25.
3. Tehnogennoe mineralnoe syre rudnyh mestorozhdenij Kazahstana / MIID RK. — Almaty, Kazakhstan: — 122 p.
4. GOST 31108-2016 Common cements. Specifications [Electronic resource] / Meganorm // Meganorm. — [2017]. — Mode of access: https://meganorm.ru/Index2/1/4293751/4293751392.htm (accessed date: 10.09.2022).
5. GOST 8736-2014 Sand for construction works. Specifications [Electronic resource] / Meganorm // Meganorm. — [2015]. — Mode of access: https://meganorm.ru/Index2/1/4293767/4293767502.htm (accessed date: 10.09.2022).
6. GOST 2138-91 Moulding sands. General specifications [Electronic resource] / Meganorm // Meganorm. — [1993]. — Mode of access: https://meganorm.ru/Index2/1/4294832/4294832221.htm (accessed date: 10.09.2022).
7. GOST 23732-79 Water for concretes and mortars. Specifications [Electronic resource] / Meganorm // Meganorm. — [1980]. — Mode of access: https://meganorm.ru/Index/31/31616.htm (accessed date: 10.09.2022).
8. GOST 30744-2001 Cements. Methods of testing with using polyfraction standard sand [Electronic resource] / Meganorm // Meganorm. — [2002]. — Mode of access: https://meganorm.ru/Index2/1/4294847/4294847911.htm (accessed date: 10.09.2022).
9. GOST 310.2-76 Cements. Methods of grinding fineness determination [Electronic resource] / Meganorm // Meganorm. — [1978]. — Mode of access: https://meganorm.ru/Index/34/34110.htm (accessed date: 10.09.2022).
10. ST RK 1217-2003 Sand for construction work. Testing methods [Electronic resource] / KazLaws // KazakhstanLaws. — [2005]. — Mode of access: https://www.kazakhstanlaws.com/p-22202-st-rk-1217-2003.aspx (accessed date: 10.09.2022).
11. Uranium Association with Iron-Bearing Phases in Mill Tailings from Gunnar, Canada / G. Othmane, T. Allard, G. Morin, M. Sélo, J. Brest, I. Llorens, N. Chen, J.R. Bargar, M. Fayek, G. Calas // Environmental Science & Technology. — 2013. — Vol. 47, No. 22. — P. 12695–12702. https://doi.org/10.1021/es401437y
12. GOST 30108-94 Building materials and elements. Determination of specific activity of natural radioactive nuclei [Electronic resource] / Meganorm // Meganorm. — [1995]. — Mode of access: https://meganorm.ru/Index2/1/4294853/4294853068.htm (accessed date: 10.09.2022).

13. GOST 10180-2012 Concretes. Methods for strength determination using reference specimens [Electronic resource] / Meganorm // Meganorm. — [2013]. — Mode of access: https://meganorm.ru/Index2/1/4293782/4293782275.htm (accessed date: 10.09.2022).
14. GOST 13087-2018 Concretes. Methods of abrasion test [Electronic resource] / Meganorm // Meganorm. — [2019]. — Mode of access: https://meganorm.ru/Index2/1/4293730/4293730304.htm (accessed date: 10.09.2022).
15. GOST 10060-2012 Concretes. Methods for determination of frost-resistance [Electronic resource] / Meganorm // Meganorm. — [2014]. — Mode of access: https://meganorm.ru/Index2/1/4293782/4293782220.htm (accessed date: 10.09.2022).
16. GOST 31383-2008 Protection against corrosion of concrete and reinforced concrete constructions. Test methods [Electronic resource] / Meganorm // Meganorm. — [2010]. — Mode of access: https://meganorm.ru/Index2/1/4293822/4293822418.htm (accessed date: 10.09.2022).
17. Compositional slag-alkaline binders, mortars and concretes on their base / N.R. Rakhimova // Russian Journal of Building Construction and Architecture. — 2008. — Vol. 12, No. 4. — P. 110–118.
18. Optimization of Cement-Based Mortar Containing Oily Sludge Ash by Response Surface Methodology / M.U. Kankia, L. Baloo, N. Danlami, W.N. Samahani, B.S. Mohammed, S. Haruna, A.H. Jagaba, M. Abubakar, E.A. Ishak, K. Sayed, N. Amila Bt Wan Zawawi // Materials. — 2021. — Vol. 14, No. 21. — P. 6308. https://doi.org/10.3390/ma14216308
19. Study of cement binders applicable for modified cast-in-place concrete / K. Khonjo, Y. Toleuov, A. Azbergenova, A. Urumbayeva // Technobius. — 2022. — Vol. 2, No. 3. — P. 0022. https://doi.org/10.54355/tbus/2.3.2022.0022
20. The composition and structure of the slag-alkaline composite binder stone with an addition of used moulding mixture / N.R. Rakhimova // News of higher educational institutions. Construction. — 2008. — Vol. 589, No. 1. — P. 45–49.
21. The use of man-made waste in the production of building materials / F. Yuldashev, G. Begzhanova // Universum:Technical sciences. — 2022. — Vol. 97, No. 4–10. https://doi.org/10.32743/UniTech.2022.97.4.13504
22. Investigation of binder compositions using waste from the production of ferrous metallurgy / T.B. Akhmetzhanov, B.S. Ashimova, E.T. Ashimova // Epoha nauki. — 2019. — No. 20. — P. 110–115. https://doi.org/10.24411/2409-3203-2019-12019
23. Optimization of the structure of the concrete of a high specific weight using fine-grained admixture / S.P. Gorbunov // Vestnik Yuzhno-Uralskogo gosudarstvennogo universiteta. Seriya: Stroitelstvo i arhitektura. — 2012. — Vol. 17, No. 14. — P. 30–35.
24. Slag Substitution as a Cementing Material in Concrete: Mechanical, Physical and Environmental Properties / M.E. Parron-Rubio, F. Perez-Garcia, A. Gonzalez-Herrera, M.J. Oliveira, M.D. Rubio-Cintas // Materials. — 2019. — Vol. 12, No. 18. — P. 2845. https://doi.org/10.3390/ma12182845

Information about authors:
Zulfiya Aubakirova – MSc, School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan, aubakirova.zulfiya@mail.ru
Aldiyar Temirbekov – MSc, School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan, asira92@bk.ru
Monika Kulisz – PhD, Associate Professor, Department of Management, Lublin University of Technology, Lublin, Poland, m.kulisz@pollub.pl
Gulnaz Zhairbaeva – MSc, School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan, gulnaz.w@mail.ru

Author Contributions:
Zulfiya Aubakirova – concept, methodology, funding acquisition.
Aldiyar Temirbekov – analysis, resources, visualization.
Monika Kulisz – interpretation, editing.
Gulnaz Zhairbaeva – data collection, testing modeling, drafting.

Received: 03.07.2022
Revised: 31.08.2022
Accepted: 01.09.2022
Published: 30.09.2022

Technobius, 2022, 2(3), 0025, DOI: https://doi.org/10.54355/tbus/2.3.2022.0025

Technobius

https://technobius.kz/

e-ISSN
2789-7338

Article

Conceptual model of noise monitoring system for construction projects in cramped conditions, based on sensors and GIS

Yelbek Utepov, Alisher Imanov*

Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
*Correspondence: glad.alisher@gmail.com

Abstract. Existing sound measuring equipment are mostly designed for indoor use, and those of outdoor are costly and demands human involvement multiple times. This study proposes the concept of a compact and cheap sensor and GIS-based system that runs algorithms of sound distribution and visualizes interpolated and extrapolated data as heatmaps in an interactive map. According to the concept, the system consists of several noise measuring devises wirelessly connected to a data collector that transmits the measurement data real-time through internet to a server, where the data is analyzed and visualized. The integrated into GIS algorithms are designed to identify the sound sources and locations where the sound level exceeded its daytime or nighttime standard limits. The implementation of proposed concept may make noise issues related to construction activities more transparent.
Keywords: acoustics, construction noise, monitoring, sensors, GIS.

1. Introduction

Construction noise can be considered as one of the most annoying phenomena for the residents of nearby buildings. This is an important aspect that must be taken cared of during any kind of cramped construction in urban area [1], since its certain levels can have a negative impact on the surrounding environment and human being. These levels are characterized by the Sound Pressure Level (SPL) arising at certain point, the tolerant ranges of which are described in [2-3]. SPL (L_p) is classically measured in Decibels (dB). The so called “loudness” that human perceives is highly related to SPL, sound frequency and duration [4], and may be measured using “equal-loudness contour” (Figure 1) when the constant loudness is perceived [2].

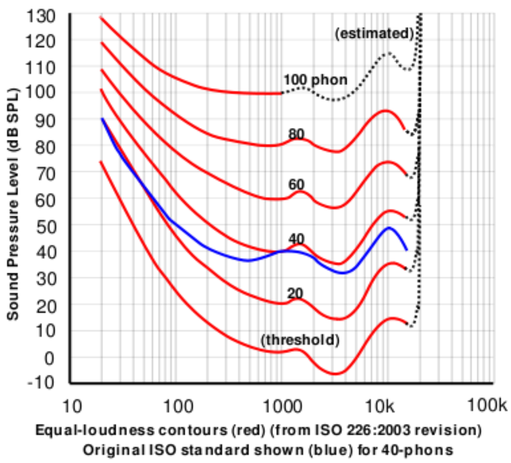

Figure 1 – Equal-loudness contours with frequency in Hz [2]

Depending on SPL the noise affect human variously. For example, a noise level of 20-30 dB is absolutely harmless, without which human life is impossible. Noise around 60 dB can be annoying, and 65-80 dB can have physiological effects. Noise level more than 85 dB leads to disorders of hearing organs. The level of noise more than 120 dB can have mechanical impact on the whole body of human, and at 130-150 dB a pain threshold is reached [5-6]. The permissible levels of noise in residential and public buildings, as well as surroundings of urban areas under construction are regulated by local sanitary rules and norms, and hygienic standards of each country. In Kazakhstan, for example, the general noise standards are regulated by [7] and controlled by [8]. Some types of economic activities are regulated by specific requirements for the level and nature of noise, for example [9]. According to these standards, the noise level at day and night should not exceed 55 and 45 dB respectively. For the registered violations of the established noise limits, there are administrative penalties and fines [10].

Unfortunately, there everywhere many cases of the violations of noise limits during the construction [11-12]. However, it is possible to question the evidence of certain cases of noise violations by construction organizations, despite the fact that due to complaints from the neighbors these organizations had to pay large penalties in order to avoid delays in the construction process. Most likely, such scenarios occur many times due to no specialized equipment is used for monitoring and registering noise pollution in and around the construction sites. Modern acoustic monitoring systems propose a variety of functionalities and a great quality, but majority of them are built for indoor use and may be unaffordable for small scale construction project budget. Outdoor ones mostly measure noise for short-term at certain point where they are located and are also costly [13-14]. Absence of continuous visualization or real time mapping of noise pollution without human or desktop software input is another disadvantage of existing systems [15].

Considering that currently used acoustic monitoring systems are costly and still do not fully cover the needs of cramped construction in urban areas, this study is aimed on structuring the concept of an easy-to-use and affordable system for real-time monitoring of noise level in construction sites.

2. Methods

To structure the concept of urban construction noise monitoring system the following aspects are consistently considered: specifics of construction in cramped conditions; regulatory support; nature of noise distribution and related parameters; functional architecture of the system; sensor capabilities and mechanism; sensor allocation strategies; and visualization techniques.

The SPL is calculated as following [16]:

$$L_{p_i} = 20\log_{10}\left(\frac{p_i}{p_{ref}}\right) = 10\log_{10}\left(\frac{p_i}{p_{ref}}\right)^2, \quad (1)$$

where: p – sound pressure (Pa); p_{ref} – reference pressure, 2×10^{-5} Pa.

Since the majority of noise in the construction site have no direction [17], the sound there takes a spherical nature. According to [18], the sound pressure measured in a certain distance (d) from the spherical sound source decreases by $1/d$, which is called an “inverse-proportional law”. From the latter it follows that having the sound pressure at one point located at a certain distance from the sound source, it is possible to calculate the sound pressure at any other point knowing the distance from it to the sound source:

$$p_{i+1} = \frac{d_i}{d_{i+1}} \cdot p_i, \quad (2)$$

where: n – ordinal number of a point, where the sound pressure d is measured.

The inverse-proportional law also states that the SPL at any point can be calculated based on any other point if the distances from these points to the sound source are known:

$$L_{p_{i+1}} = L_{p_i} + 20\log_{10}\left(\frac{d_i}{d_{i+1}}\right), \quad (3)$$

As mentioned by [17], the noise in construction site may be produces simultaneously at several locations with various SPLs. Therefore, an accurate detection of the sound source location and measure of the sound pressure there in-time and simultaneously is almost impossible physically. To solve this task this study proposes to assume that the points with known values of sound pressure (i.e., those where the SPL is measured) are equivalent to those of sound source; so that the inverse problem is considered. In this case, assuming that the sound waves are distributed from the measured points, at certain distances in-between these waves somehow collide where a particular rule or equation should be used to determine the combined SPL multiple sound sources (i.e., measured points). In this case a sum of SPLs is taken as:

$$L_{p_\Sigma} = 10\log_{10}\left(\sum_i^n\left(\frac{p_i}{p_{ref}}\right)^2\right), \quad (4)$$

From the Equation 1 and basic logarithmic rules derived:

$$\left(\frac{p_i}{p_{ref}}\right)^2 = 10^{\frac{L_{p_i}}{10}}, \quad (5)$$

Therefore, when combining Equations 4 and 5 we find:

$$L_{p_\Sigma} = 10\log_{10}\left(\sum_i^n 10^{\frac{L_{p_i}}{10}}\right), \quad (6)$$

For the considered case Equation 6 can be used for determining the SPL at intermediate points where multiple sound waves are collided.

The functional architecture of the system includes activities taking place outdoor and indoor, as well as those of both (Figure 2).

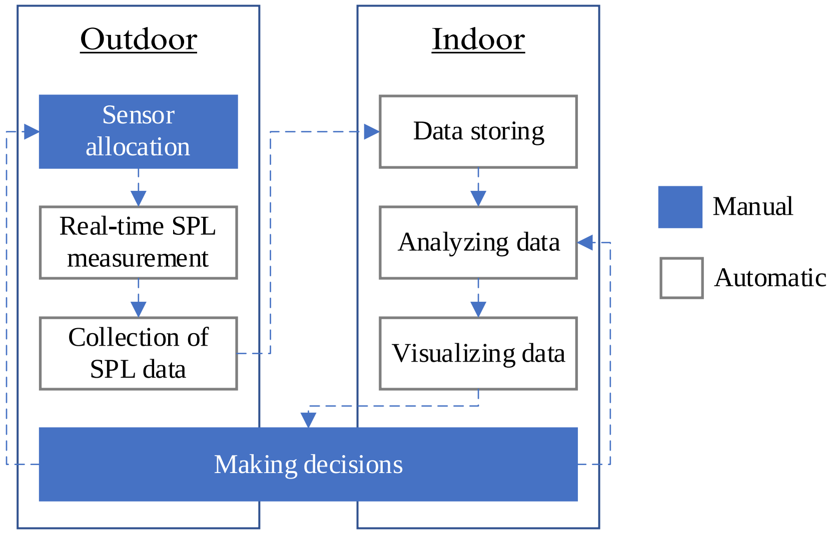

Figure 2 – Functional architecture of the system

As shown in the architecture above, majority of processes are performed automatically. This becomes possible with a combination of various components, such as electronic devices, wireless technologies, cloud storages, different algorithms, and online user interface. Manual work is reduced to a minimum to reduce human error, increase accuracy, and save time and resources.

The system should detect and record the events of noise limit violations, visualize locations where certain event happened and when happened, as well as present real-time SPL values at any point of construction site and nearby buildings.

Based on the experience of previous experience [19-20], for each construction site there should be two types of electronic devices: several measuring devices and a single data collector. Communication between these devices must be provided by small-sized wireless technology, working at distances corresponding at least to the dimensions of the construction site. Experience on similar studies [21] show that the wireless technology "Lora" perfectly meets such demand.

Since the construction site is characterized by its own chaos, where machines, mechanism, and workers are always in action, the measuring device should be also transportable, easy to recognize, handy and lightweight, as well as rigid when installed for certain reasons, such as: to avoid damage due to heavy equipment movement, to quickly locate and relocate, as well as to ease installation. For such specifications, the most suitable device design appears to be a vertical rod with a pin at the bottom and electronic components at the top. Electronic components should be put into the rugged housing and include at least microcontroller, battery, Lora module, and microphone sensor. The measuring devices should be allocated to the construction site based on certain strategy, taking into account surrounding features and their positions (e.g., existing infrastructure and neighboring buildings).

The data collector should have a housing, microcontroller, both rechargeable battery and 220V power connection, Lora module, USB slot, memory card, and internet module. It should continue working for some hours even when not connected to 220V without loss of collected data.

The system should include also a server-side containing a database and web application to store, analyze and visualize data received real-time. Analysis made real-time should be based on the algorithms of SPL estimation, as well as interpolation and extrapolation techniques.

3. Results and Discussion

Figure 3 below presents the concept of noise measuring device.

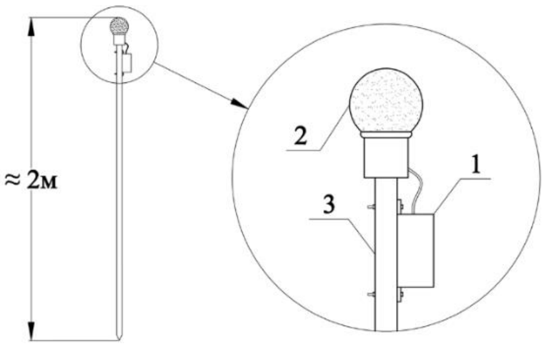

Figure 3 – Concept of noise measuring device

The proposed concept of noise measuring device consists of three main parts: housing (1) where majority of electronic components are located; microphone sensor (2) attached to the top; vertical rod (3) with a pointed end, where all components are fixed. The rod must be made of corrosion-resistant metal, preferably aluminum, to withstand harsh weather conditions. It is expected to be driven into the ground to a depth sufficient to hold it firmly in a vertical position.

The schematic concept of electronic devices of the system is presented below (Figure 4).

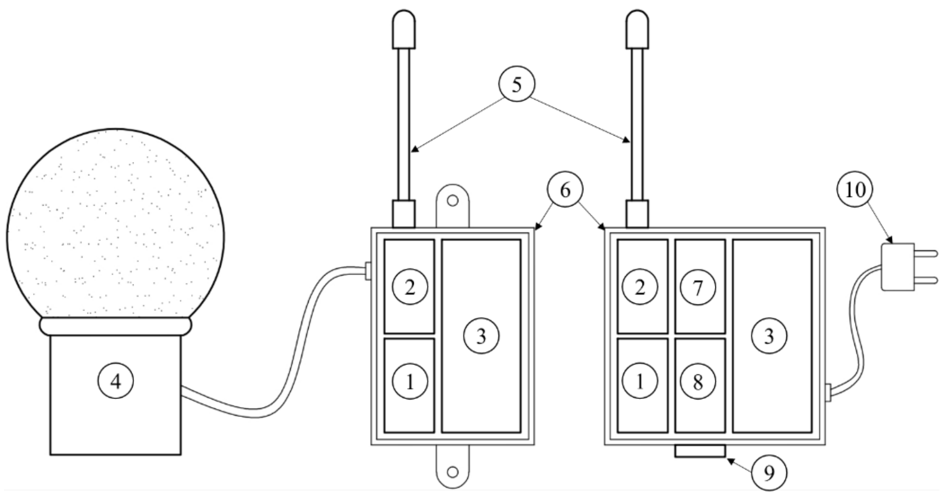

Figure 4 – Electronic components

According to the Figure 4 above, the electronic components of the system include: microcontroller (1), Lora module (2), battery (3), microphone sensor (4), antenna (5), housing (6), internet module (7), memory module (8), USB slot (9), and 220V plug (10).

The server-side of the system proposed can be constructed using phpMyAdmin or pgAdmin running the MySQL or PostgreSQL relational databases. The web GIS application can be constructed using OpenLayers opensource Javasript API, or commercial version of Leaflet Javasript API. The general concept of the GIS application performance is presented below (Figure 5). The presented picture was constructed using opensource application called FNM [22].

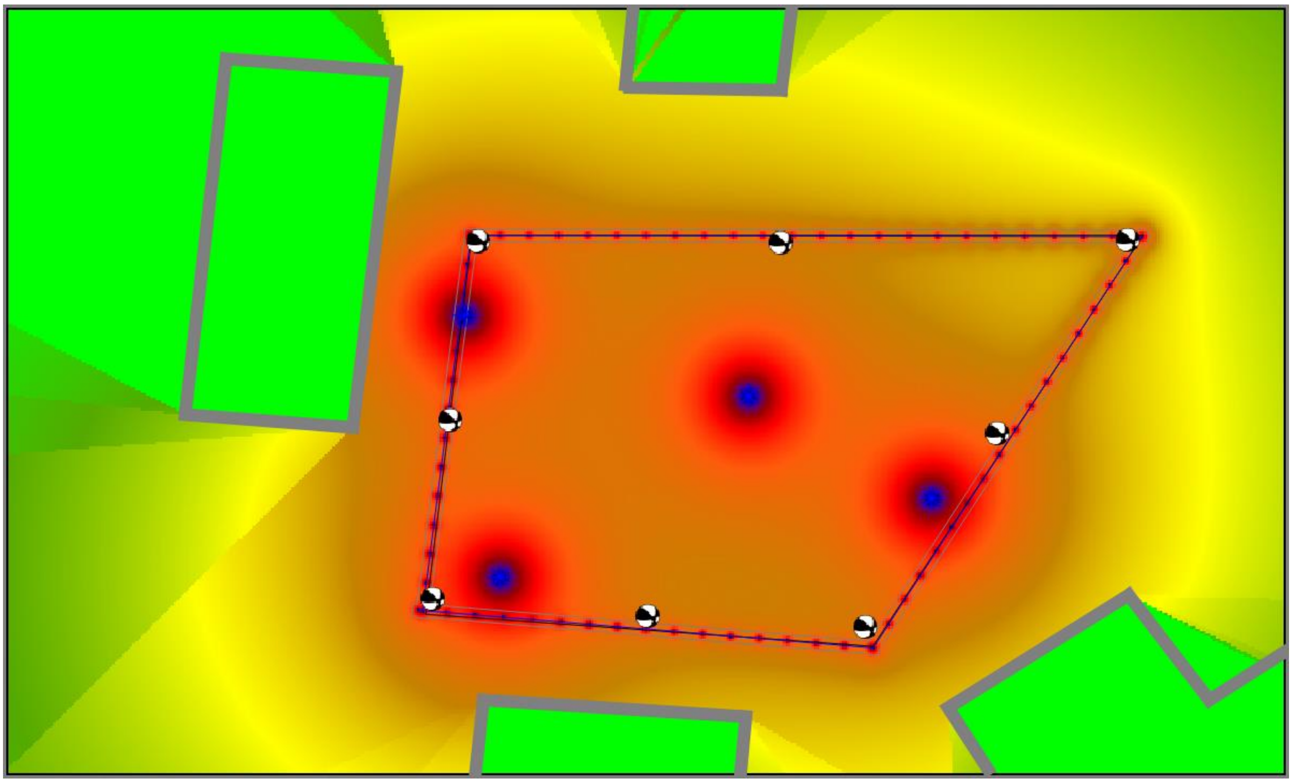

Figure 5 – Visual concept of noise monitoring in the construction site

Figure 5 above shows the virtual model of the fenced area of the construction site along with neighboring buildings. It is seen that there are 4 sources of noise marked with star-sign, from which the sound waves are distributed spherically. The noise measuring devices are installed on the corners and centers of fences. It is expected that the integrated into the web GIS application algorithm that is based on solving an inverse task expressed by Equations 1-6 along with the interpolation (extrapolation) techniques will give similar picture of the sound distribution in a heatmap manner. Based on known values of SPL, the algorithm should be able to calculate and indicate the locations of the so called “hotspots”, which are nothing else than the sound source locations, as well as it should record, show and alarm when the standard limits of SPL are identified anywhere in the map.

4. Conclusions

Review of previous studies revealed that existing noise monitoring systems for construction sites rather measure sound in discrete character and disable estimation of SPL in any other location based on known values, considering the sound as a continuous phenomenon. These systems are expensive and require direct human involvement (i.e., the operator).

Proposed concept is intended to cheapen the cost of noise monitoring system making it almost autonomous. The concept of the system includes noise measuring devices that communicate with data collector remotely using Lora wireless technology, as well as server-side containing database and web GIS application. The GIS application visualizes the data retrieved remotely from the data collector and runs special algorithms. The result is the interactive heatmap of sound distribution over the virtual construction site and surrounding buildings that is updated real-time.

Further studies will be focused on testing and selecting the system components proposed in the concept, as well as assembling and pilot testing of the system. The implemented system in the future enables transparency in the construction noise related issues.

References

1. Evaluation of Building Construction-Induced Noise and Vibration Impact on Residents / C. Zou, R. Zhu, Z. Tao, D. Ouyang, Y. Chen // Sustainability. — 2020. — Vol. 12, No. 4. — P. 1579. https://doi.org/10.3390/su12041579
2. ISO 226:2003 Acoustics - Normal equal-loudness-level contours / ISO2003. — 18 p.
3. Bone conduction equal-loudness: A comparison of AC/BC equal-loudness curves in an open vs. Closed ear listening environment / R. Patrick, J. Kring, M. McBride, T. Letowski // IIE Annual Conference and Expo 2014. — 2014. — P. 2839–2846.
4. Loudness of tone pulses in a free field / T. Poulsen // The Journal of the Acoustical Society of America. — 1981. — Vol. 69, No. 6. — P. 1786–1790. https://doi.org/10.1121/1.385915
5. Effects of Noise Pollution on Human Health / R.N. Pantawane, K.V. Maske, N.S. Kawade // International Advanced Research Journal in Science, Engineering and Technology. — 2017. — Vol. 4, No. 3. — P. 33–35. https://doi.org/10.17148/IARJSET
6. Decibel Hell: The Effects of Living in a Noisy World / R. Chepesiuk // Environmental Health Perspectives. — 2005. — Vol. 113, No. 1. — P. A34–A41. https://doi.org/10.1289/ehp.113-a34
7. SanPiN № 3.01.030-97 Predelno-dopustimye urovni infrazvuka i nizkochastotnogo shuma v pomesheniyah zhilyh i obshestvennyh zdanij i na territorii zhiloj zastrojki [Electronic resource] / E.E. Durumbetov // PARAGRAPH information system. — [1997]. — Mode of access: https://online.zakon.kz/Document/?doc_id=30010457 (accessed date: 01.08.2022).
8. Metodicheskie ukazaniya po osushestvleniyu gosudarstvennogo sanitarno-epidemiologicheskogo nadzora za soblyudeniem SanPiN RK № 3.01.035-97 [Electronic resource] / E.E. Durumbetov // PARAGRAPH information system. — [1997]. — Mode of access: https://online.zakon.kz/Document/?doc_id=30010483 (accessed date: 01.08.2022).
9. Ob utverzhdenii norm shumovyh i inyh akusticheskih vozdejstvij iskusstvennogo proishozhdeniya [Electronic resource] / Adilet // Legal information system of Regulatory Legal Acts of the Republic of Kazakhstan. — [2015]. — Mode of access: https://adilet.zan.kz/rus/docs/V1500012387 (accessed date: 01.08.2022).
10. On Administrative Infractions [Electronic resource] / Adilet // Legal information system of Regulatory Legal Acts of the Republic of Kazakhstan. — [2014]. — Mode of access: https://adilet.zan.kz/eng/docs/K1400000235 (accessed date: 01.08.2022).
11. Bez prava na tishinu [Electronic resource] / Yu. Korosteleva // Analytical online magazine Vlast'. — [2022]. — Mode of access: https://vlast.kz/gorod/49839-bez-prava-na-tisinu.html (accessed date: 01.08.2022).
12. What Are Your Rights When It Comes to Nearby Construction? [Electronic resource] / J. Nesbit // US News & World Report. — [2020]. — Mode of access: https://realestate.usnews.com/real-estate/articles/what-are-your-rights-when-it-comes-to-nearby-construction (accessed date: 01.08.2022).
13. The implementation of low-cost urban acoustic monitoring devices / C. Mydlarz, J. Salamon, J.P. Bello // Applied Acoustics. — 2017. — Vol. 117, No. Part B. — P. 207–218. https://doi.org/10.1016/j.apacoust.2016.06.010
14. Measurement and sonification of construction site noise and particle pollution data / N. Rönnberg, R. Ringdahl, A. Fredriksson // Smart and Sustainable Built Environment. — 2022. — Vol. 12, No. 4. — P. 742–746. https://doi.org/10.1108/SASBE-11-2021-0189
15. Mapping and analyzing the construction noise pollution in China using social media platforms / Y. Wang, G. Wang, H. Li, L. Gong, Z. Wu // Environmental Impact Assessment Review. — 2022. — Vol. 97. — P. 106863. https://doi.org/10.1016/j.eiar.2022.106863
16. Architectural Acoustics / M. Long. — Amsterdam, Netherlands: Elsevier, 2014. — 984 p. https://doi.org/10.1016/C2009-0-64452-4
17. Environmental Impact of Construction Site Activities in Ghana / J. Ayarkwa, A. Acheampong, J.K. Hackman, K. Agyekum // Africa Development and Resources Research Institute (ADRRI) journal. — 2014. — Vol. 9, No. 2. — P. 1–19.
18. Geometrical and physical optics / R.S. Longhurst. — London: Longman, 1967. — 622 p.
19. Performance of a wireless sensor adopted in monitoring of concrete strength / Ye.B. Utepov, A.S. Tulebekova, A.K. Aldungarova, Sh.Zh. Zharassov, E.E. Sabitov // International Journal of GEOMATE. — 2022. — Vol. 23, No. 95. — P. 73–80. https://doi.org/10.21660/2022.95.3265

20. Performance of maturity method for estimation of concrete strength based on cubic specimens / R. Lukpanov, S. Zharassov, T. Mkilima, A. Aldungarova // Technobius. — 2021. — Vol. 1, No. 4. — C. 0008. https://doi.org/10.54355/tbus/1.4.2021.0008
21. Performance of Maturity Sensor Based on LoRaWAN Network / Y. Utepov, A. Aniskin, A. Tulebekova, S. Zharassov, A. Aldungarova // Trudy Universiteta. — 2021. — Vol. 84, No. 3. — P. 232–240. https://doi.org/10.52209/1609-1825_2021_3_232
22. Free Noise Map [Electronic resource] / C.C.V. MESA. — [2021]. — Mode of access: https://christian-mv.github.io/Free_Noise_Map_Demo/FreeNoiseMap.html (accessed date: 01.08.2022).

Information about authors:
Yelbek Utepov – PhD, Acting Professor, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, utepov-elbek@mail.ru
Alisher Imanov – PhD Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, glad.alisher@gmail.com

Author Contributions:
Yelbek Utepov – concept, methodology, resources, analysis, editing, funding acquisition.
Alisher Imanov – data collection, modeling, testing, visualization, interpretation, drafting.

Received: 22.08.2022
Revised: 03.09.2022
Accepted: 22.09.2022
Published: 30.09.2022