UDC 727
IRSTI 67.07
RESEARCH ARTICLE

ANALYSIS AND EVALUATION OF EXPERIMENTAL METHODS FOR DETERMINING THE STRENGTH OF CONCRETE

M.Z. Praliyeva[1]*, **Z.T. Nashiraliyev[2]**, **U.T. Begaliev[3]**

[1,2]Kazakh National Technical University after K.I. Satbayev, 050013, Almaty, Kazakhstan
[3]International University of Information Technology Corporation, 720044, Bishkek, Kyrgyzstan

Abstract. *The study presents an overview of several experimental techniques used to determine the strength and bearing capacity of concrete. During the research, special attention was paid to how the quality of the mix and curing conditions influence the reliability of the results. The experiments were carried out on cube, prism, and cylinder specimens that were tested at different stages of hardening. The obtained data helped to trace how the internal structure of concrete changes with time and to identify the factors that most strongly affect its load resistance. Compressive and flexural strengths were determined using three specimen types: cubes, prisms, and cylinders. Ten samples of each shape were produced and tested at different ages over a curing period of 180 days. These experiments allowed calculation of the coefficient of variation and tracking of strength development over time. Results showed that destructive testing provides dependable data on the mechanical response of concrete under load. The total specimen volume did not significantly influence strength; however, widening the cross-sectional area at the upper surface tended to reduce resistance and foster the formation of micro-cracks. Conversely, smaller sections demonstrated higher strength values and more stable variation coefficients. The findings also underline the limitations of relying solely on average strength indicators.*

Keywords: *prism, concrete, load, strength, bending, compression, standard deviation.*

***Corresponding author**
Mariyam Praliyeva, e-mail: mariyam333@inbox.ru

https://doi.org/10.51488/1680-080X/2025.3-08
Received 01 July 2025; Revised 16 August 2025; Accepted 8 September 2025

ӘОЖ 727
ҒТАМР 67.07
ҒЫЛЫМИ МАҚАЛА

БЕТОННЫҢ БЕРІКТІГІН АНЫҚТАУДЫҢ ЭКСПЕРИМЕНТТІК ӘДІСТЕРІН ТАЛДАУ ЖӘНЕ БАҒАЛАУ

М.Ж. Пралиева[1]*, Ж.Т. Наширалиев[2], У.Т. Бегалиев[3]

[1,2]Қ.И.Сәтбаев атындағы ҚазҰТЗУ, 050013, Алматы, Қазақстан
[3]Халықаралық ақпараттық технологиялар университеті, 720044, Бішекек, Қырғызстан

Аңдатпа. *Мақалада бетонның беріктік қасиеттерін бағалау және оның жүктемені көтеру қабілетін анықтау әдістері қарастырылды. Эксперименттік сынақтар барысында әртүрлі формадағы үлгілердің сыну ерекшеліктері талданды. Зерттеудің маңызды бөлігі-бетон сапасын жүйелі бақылау. Себебі сенімді ақпарат жинау болашақта ғимараттар мен құрылымдық элементтердің беріктігін, сондай-ақ ұзақ мерзімді жұмыс қабілеттілігін қамтамасыз етеді. Сондықтан нақты жағдайда дұрыс әдісті таңдау, сонымен қатар бетонның ішкі құрылымына назар аудару аса өзекті міндет болып табылады. Зерттеудің негізгі мақсаты – материалдың сығылуға және иілуге беріктік көрсеткіштерін анықтау үшін сыну әдістерін қолдану болды. Осы мақсатта үш түрлі үлгі формасы дайындалды: куб, призма және цилиндр. Әр форма бойынша он данадан үлгілер әзірленіп, 180 күн бойы сынақтан өткізілді. Үлгілерге жүргізілген тәжірибелердің нәтижесінде вариациялық коэффициент есептелді, сондай-ақ уақыт өте келе беріктіктің өзгеруі бақыланды. Нәтижелер көрсеткендей, сындыруға негізделген әдістер бетонның механикалық қасиеттерін дәлірек бағалауға мүмкіндік береді. Ал бұзбайтын әдістер тек қосымша бақылау құралы ретінде тиімді, бірақ негізгі бағалау үшін жеткіліксіз. Тәжірибе бетон элементінің жалпы көлемі беріктікке айтарлықтай әсер етпейтінін дәлелдеді. Дегенмен, үлгінің жоғарғы кесім аймағының ұлғаюы беріктікті төмендетіп, микрожарықтардың пайда болуына ықпал етті. Керісінше, кішігірім қималар жоғары беріктік мәндерін көрсетіп, вариация коэффициентінің тұрақтылығын арттырды. Сонымен қатар, тек орташа деректерге сүйену қателіктерге алып келуі мүмкін. Әрбір конструкциялық элемент үшін жеке беріктік көрсеткіштерін таңдау – құрылымдық қауіпсіздікті қамтамасыз етудің маңызды шарты. Бұл ғылыми тұжырымдар құрылыс саласында сапаны арттыруға және инженерлік шешімдердің сенімділігін күшейтуге бағытталған.*

Түйін сөздер: *призма, бетон, жүктеме, беріктік, иілу, сығу, стандартты ауытқу.*

***Автор-корреспондент**
Мариям Пралиева, e-mail: e-mail: mariyam333@inbox.ru

https://doi.org/10.51488/1680-080X/2025.3-08
Алынды 01 шілде 2025; Қайта қаралды 16 тамыз 2025; Қабылданды 08 қыркүйек 2025

УДК 727
МРНТИ 67.07
НАУЧНАЯ СТАТЬЯ

АНАЛИЗ И ОЦЕНКА ЭКСПЕРИМЕНТАЛЬНЫХ МЕТОДОВ ОПРЕДЕЛЕНИЯ ПРОЧНОСТИ БЕТОНА

М.Ж. Пралиева[1]*, Ж.Т. Наширалиев[2], У.Т. Бегалиев[3]

[1,2]КазНИТУ имени К.И.Сатпаева, 050013, Алматы, Казахстан
[3]Международный университет информационных технологий, 720044, Бишкек, Кыргызстан

Аннотация. *В этой статье проведен анализ методов характеристик прочности бетона и его несущей способности. Выполнен анализ испытанных образцов экспериментальным методом на разрушение. Важной частью данного исследования является контроль качества бетона, поскольку успех сбора информации по данному материалу несет в себе дальнейшую несущую способность элементов каркаса зданий и сооружений. Поэтому в наши дни очень важным является подбор правильного в конкретном случае метода экспериментального исследования, уделяя большое внимание структурной сетке бетона. Перед собой мы поставили цель провести экспериментальные разрушающие методы для выявления оценочного показателя прочностной характеристика данного материала на сжатие, а также на изгиб. Поэтому в первую очередь задача была в том, чтобы подготовить три формы образцов из куба, призмы и цилиндра. Затем по готовности были выполнен эксперимент разрушающего метода, выявление вариативного коэффициента. Были испытаны 10 видов образцов каждой формы на протяжении 180 дней влияния прочности бетона. По результату сделан вывод, что данный метод эксперимента помогают получить точные данные поведения прочности бетона и его дальнейшей эксплуатации строительной конструкции, причем, при любых возможных условиях, нежели метод неразрушающий, который использовать можно как дополнительный для контроля качества бетонной конструкции. Данный эксперимент показал, что объем конструкции элемента на прочность не влияет. Но подводя итоги выявилось, что если увеличить площадь на верхнем сечении, то снизится прочностные свойства бетона, соответственно и приведет к нежелательным микрофракциям. Повышение несущей способности бетона, коэффициент вариации прочности связано с небольшими сечениями испытываемых образцов.*

Ключевые слова: *призма, бетон, нагрузка, прочность, изгиб, сжатие, среднеквадратичное отклонение.*

***Автор-корреспондент**
Мариям Пралиева, e-mail: e-mail: mariyam333@inbox.ru

https://doi.org/10.51488/1680-080X/2025.3-08
Поступило 01 июля 2025; Пересмотрено 16 августа 2025; Принято 08 Сентября 2025

ACKNOWLEDGEMENTS/SOURCE OF FUNDING

The research was conducted using private sources of funding.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

The authors declare that no generative artificial intelligence technologies or AI-based tools were used in the preparation of this article.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Авторлар мақаланы дайындау барысында генеративті жасанды интеллект технологиялары мен жасанды интеллектке негізделген технологияларды пайдаланбағанын мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

Авторы заявляют о том, что при подготовке статьи не использовались технологии генеративного искусственного интеллекта и технологии, основанные на искусственном интеллекте.

1 INTRODUCTION

In modern construction practice, ensuring the reliability of reinforced concrete structures remains one of the most important engineering challenges. Although various national and international standards regulate the classification of concrete strength, the practical application of these methods still raises questions regarding their accuracy and comparability.

In our study, we focused on evaluating the actual strength of concrete using different specimen shapes and testing techniques. The experiments were performed at Vilnius Gediminas Technical University (VILNIUS TECH, Lithuania) with the use of a servo-hydraulic testing machine LVF5000 (capacity 5 MN, WALTER + BAI AG, Switzerland). The load was applied gradually under the control of DION 7 software, while all measurements were automatically recorded using the ALMEMO 5690-2 system.

Before fabricating the experimental reinforced concrete beams, we verified the quality of the mix and compliance of materials with technical standards to prevent premature failure. In this context, special attention was paid to the selection of aggregates and the control of curing conditions, since both directly affect the load-bearing performance of structural elements.

In practice, the strength of concrete represents its ability to resist external forces without visible damage or internal cracking. This property largely depends on the homogeneity of the mixture and the proportion between cement, water, and aggregates. Therefore, each batch must be tested to confirm that the material meets design requirements and provides sufficient safety margins for long-term use.

Taking these aspects into account, the current research aimed to analyze destructive testing methods for determining the compressive and flexural strength of concrete. Following the recommendations of the national standard ST RK ISO 1920-6-2009 “Testing of Concrete. Part 6. Sampling, preparation and testing of reinforced concrete frames,” destructive testing was selected as the main experimental approach, as it allows for the most accurate assessment of real mechanical behavior under load.

2 LITERATURE REVIEW

Research on concrete has been conducted for nearly a century, resulting in a substantial body of knowledge regarding the influence of concrete properties on the structural characteristics of construction projects. The experience of the Russian school of design has consolidated this knowledge, emphasizing the fundamental factors affecting concrete strength as well as its impact on the overall performance of structures.

Notable contributions have been made by authors such as **(Bazhenova Y.M. & Kolchunova V.I., 2005)**, who focused on the effects of the material’s structural form on the outcomes of destructive testing of concrete. Further insights were provided by **(Loganina V.I., 2014)** and **Krivenya S.M., 2018)**, whose work contributed to understanding the behavior of compacted concrete, highlighting the critical role of concrete strength in both bending and compression performance.

Research in Kazakhstan has been conducted taking into account the available raw material resources as well as the climatic conditions of the country. Studies by **(Lukpanova R. et al., 2021)** focused on the influence of concrete strength characteristics using cubic samples. The work of **(Begentayev M. et al., 2025)** addressed the assessment of compressive strength with the use of ash additives, providing results that highlight the impact of modern admixtures and their potential application in practical construction.

Experience shows that both Russian and Kazakh research has progressed from studying basic concrete strength characteristics to developing innovative models that consider the material’s structure and proper use, which have a significant effect on the overall load-bearing capacity of structures.

The primary objective today is to optimize the use of collected material data, taking into account the influence of sample shape and testing methods on concrete strength. This need has become the central focus of the present study, emphasizing the importance of accurate assessment methods to ensure both safety and durability in construction applications.

3 MATERIALS AND METHODS

At the laboratory of Vilnius Gediminas Technical University (VILNIUS TECH), samples of three types were prepared: cylinders, cubes, and prisms. Specifically, ten cylindrical samples with a diameter of Ø150 mm and a height of 300 mm were prepared, ten prism samples with a cross-section of 100×100×400 mm, and ten cubic samples measuring 150×150×150 mm.

The experimental-laboratory investigations were conducted in several stages: an examination of the current state of research has shown a lack of approaches for analyzing the strength of small-sized cylindrical and cubic specimens; the formulation of theoretical principles for evaluating concrete strength, grounded in the previously proposed failure model; cconducting multiple experimental investigations on the stress–strain behavior of concrete specimens, with variation of the key parameters influencing their strength; conducting experimental testing of concrete specimens.

The main concrete specimens in the form of cylinders and cubes were prepared in the laboratory of Vilnius Gediminas Technical University (VILNIUS TECH) using a concrete mixer, as shown in **Figures 1-5.**

Figure 1 – Concrete mixer unit (author's materials)

Metallic collapsible molds were used for specimen preparation. The concrete mix was compacted using vibrators operating at a frequency of 2,500 semi-oscillations per minute with an amplitude of 0.45 mm. During the spring–summer period, specimens were prepared under natural curing conditions. The ambient air temperature during casting ranged from 15 to 19°C. Demolding was carried out 5-6 days after casting. Prior to testing, all specimens were stored in moist sawdust to maintain adequate humidity.

Figure 2– Concrete Mix Preparation (author’s materials)

During the casting of concrete samples in the form of cylinders and cubes, special molding forms were used, as shown in Figure 3. Metal collapsible molds were employed to shape the samples. The concrete mixture was compacted using vibrators operating at a frequency of 2,500 half-cycles per minute with an amplitude of 0.45 mm. In the spring and summer season, samples were produced under conditions of natural curing. The ambient temperature during sample preparation averaged between 15 and 19°C. Demolding was performed 5–6 days after casting. Prior to testing, the samples were stored in moist sawdust.

Figure 3– Fabrication of Samples in the Form of Cylinders and Cubes (author’s materials)

Figure 4 – Cylinder molding form (author's materials)

Figure 5 – Cube, prisms molding form (author's materials)

Concrete specimens of three types were prepared at the laboratory of Vilnius Gediminas Technical University (VILNIUS TECH) for experimental testing: ten cylinders (Ø150 × 300 mm), ten prisms (100×100×400 mm), and ten cubes (150×150×150 mm). Prior to testing, all specimens were cured for 28 days under standard laboratory conditions to ensure uniform hydration and strength development. Each sample was visually inspected for defects such as cracks, voids, or surface irregularities, and any specimens not meeting quality criteria were excluded from the study. Dimensional measurements and mass recording were performed to confirm conformity with the specified sizes, ensuring reliability and reproducibility of results.

During testing, the stress–strain behavior of each specimen was continuously recorded using precision sensors and data acquisition systems. Observations were made on crack initiation, propagation, and final failure modes, which were documented with photographs and video recordings. These data allowed detailed analysis of the mechanical behavior of concrete under destructive loading and provided a basis for evaluating the influence of specimen geometry on compressive and flexural strength.

All tests were conducted in triplicate for each type of specimen to ensure reproducibility and reliability of the results. The recorded data were processed to calculate key mechanical properties, including compressive strength for cylindrical and cubic specimens, and flexural strength for prism specimens.

Statistical analysis was applied to determine average values and standard deviations, providing a quantitative basis for comparing the performance of different specimen types and evaluating the effect of geometry on concrete behavior. In this case, we ensured conditions in which the control concrete samples were cured in chambers with automatic maintenance of optimal temperature and humidity, as shown in **Figures 6–9.**

Before beginning the fabrication of the experimental reinforced concrete beam for strength testing, it was essential to ensure that the future structure would comply with the standards and not fail prematurely. This required verifying the quality of the construction process and the choice of building materials. In this context, careful attention must be paid to the quality of the concrete mix, with its key parameter being the material's strength characteristics.

Figure 6 – Preparation of cylinder-shaped specimens (author's materials)

Figure 7 –Preparation of cube-shaped, prism-shaped specimens, cylinder-shaped specimens (author's materials)

Figure 8 – Preparation of cube-shaped, prism-shaped specimens (author's materials)

Figure 9 – General view of the molding forms with cast concrete specimens (author's materials)

At each stage of the experiments, particular attention was paid to controlling the dimensions and quality of the specimens, proper placement in the testing machines, and accurate recording of loads and deformations. Standard compression tests were applied for cylindrical and cubic specimens, while prism specimens underwent bending tests to evaluate their flexural strength.

Specimens were prepared for experimental studies to test compression, tension, and bending; the data are presented in **Table 1**.

Table 1

Experimentally investigated variants of control specimens (author's materials)

Type of Test	Specimen Shape	Linear Dimensions, mm
Compression and Tension Testing	Cubic	with dimensions 150×150×150 mm
	Cylindrical	Ø150, h=300 mm
Axial Tension Testing	Prismatic	with dimensions from 100x100x400 mm up to 300x300x1200 mm
	Cylindrical	Ø150, h=300 mm
Flexural Strength and Tension Test	Prismatic	with dimensions from 100×100×400 mm up to 300×300×1200 mm

Some prisms were kept moist for 2 days and then subjected to steam treatment according to the following procedure: the temperature was raised to 80 ° C over three hours, maintained for 8 hours, and then reduced to 6 °C over six hours. The concrete mix was designed to produce three strength classes: low strength (classes B15 and B25), medium strength (classes B30 and B40), and high strength (class above B50). The next stage of the study involved testing the samples for compressive and flexural strength using a specialized press machine located in the laboratory of Vilnius Gediminas Technical University (VILNIUS TECH), as shown in **Figure 10**.

Figure 10 – Strength tests on a specialized press machine in the laboratory of Vilnius Gediminas Technical University (VILNIUS TECH) (author's materials)

In the laboratory, the experimental analysis of concrete properties was performed using a hydraulic press. Cube- and cylinder-shaped specimens were placed under the press, and the load was gradually increased until failure occurred, as illustrated in **Figures 11-12.**

Metallic collapsible molds were used to produce the specimens. The concrete mix was compacted using vibrators with a frequency of 2,500 semi-oscillations per minute and an amplitude of 0.45 mm. During the spring-summer period, specimens were prepared for natural curing. During specimen preparation, the ambient air temperature ranged from 15 to 19° C. Demolding was performed 5-6 days after casting. Before testing, the specimens were stored in moist sawdust.

Figure 11 – Strength tests on the specialized press machine in the laboratory of Vilnius Gediminas Technical University (VILNIUS TECH) (author's materials)

Figure 12 – Strength tests conducted on a specialized press machine in the laboratory of Vilnius Gediminas Technical University (VILNIUS TECH) (author's materials)

Two Canon EOS 77D DSLR cameras equipped with Canon EF-S 18–135 mm lenses were mounted on tripods at a distance of 2000 mm from opposite faces of the beam to capture digital images. Camera settings included a shutter speed of 1/100 s, an aperture of f/4.0, a focal length of 24 mm, and an ISO sensitivity of 100. Images with a resolution of 6000×4000 pixels were captured at each 5 kN increment of applied load. The remote-control device was used to prevent unintended displacement of the cameras. The GOM Correlate software (GOM Metrology, Germany) was employed to monitor and visualize the tensile and compressive strength tests.

4 RESULTS AND DISCUSSIONS

At this stage of the work, we compared how the shape and size of the specimens affected the compressive strength of concrete. During testing, it became clear that even small differences in geometry can slightly change the load-bearing capacity. The results are summarized below and include both direct measurements and our own observations of fracture patterns. In general, smaller samples showed higher strength values, which agrees with similar laboratory findings reported in earlier studies. The ultimate compressive force values were recorded and documented in the concrete testing protocol, with corresponding load and strength measurements summarized in **Table 2**, as presented in the results section.

Table 2

Concrete Cube Compressive Strength Test from the Experimental Study Conducted on 05.05.2023 (Author’s Materials)

05.05.2023											
								Age	**7**	**28.04.2023**	
Concrete Cube Compressive Strength Test											
1_cube			**2_cube**			**3_cube**			**4_cube**		
	Dimension mm	**Mass, gr**		**Dimension mm**	**Mass, gr**		**Dimension mm**	**Mass, gr**		**Dimension mm**	**Mass, gr**
1	151,1	8053	1	154,01	8213	1	152,3	8102	1	152,57	7953
2	151,4	V_c, mm³	2	153,58	V_c, mm³	2	151,0	V_c, mm³	2	151,51	V_c, mm³
3	151,9	3487301	3	154,22	3534168	3	153,8	3472345	3	152,56	3457472
4	151,4	p, kg/m³	4	156,47	p, kg/m³	4	150,7	p, kg/m³	4	151,31	p, kg/m³
5	151,6	2309,2	5	151,82	2323,9	5	151,3	2333,3	5	150,64	2300,2
6	152,1	Load, kN	6	151,53	Load, kN	6	151,8	Load, kN	6	150,63	Load, kN
7	152,0	881,7	7	151,92	833,8	7	150,1	946,8	7	150,20	869,7
8	152,1	$R_{15×15}$, MPa	8	151,86	$R_{15×15}$, MPa	8	150,3	$R_{15×15}$, MPa	8	150,22	$R_{15×15}$, MPa
9	150,9	38,28	9	150,80	35,54	9	151,5	41,27	9	151,24	38,04
10	151,9	A_c, mm²	10	150,96	A_c, mm²	10	151,3	A_c, mm²	10	151,32	A_c, mm²
11	150,8	23031,41	11	150,01	23461,02	11	151,7	22940,97	11	150,88	22862,34
12	151,9		12	150,79		12	150,8		12	151,48	
											$f_{m15×15}$
											38,28
									Standart deviation:		2,35

Table 2 clearly shows that the concrete strength reached 38.28 ± 2.35 MPa, indicating that, overall, the concrete curing results were within the normative range. The cameras were mounted on a tripod at a distance of 2000 mm from the opposite beam surfaces to monitor the condition of the specimens.

Before presenting the data in **Table 3**, it is important to highlight the comparative nature of the conducted experiments. **Table 2** summarizes the results of the initial series of tests, where the compressive strength of concrete cubes was measured under standard curing conditions. These values served as the baseline for further evaluation of the development of the material's mechanical properties.

In contrast, **Table 3** reflects a later stage of testing, where the compressive strength of concrete reached 44.61 MPa. This outcome indicates a progressive enhancement of the internal structure of the material during the curing process and significantly exceeds the results obtained in the previous series. A comparative analysis of **Tables 2** and **3** confirms the positive influence of curing duration on the growth of strength, which is particularly relevant for construction materials science. The higher values recorded in **Table 3** suggest the high reliability of the investigated mix and its potential applicability in structural elements requiring enhanced load-bearing capacity.

Table 3

Concrete Cube Compression Strength Test Conducted on 12.05.2023 (Author's Materials)

12.05.2023											
								Age,14		**28.04.2023**	
Concrete Cube Compressive Strength Test											
1_cube			**2_cube**			**3_cube**			**4_cube**		
Dimension mm		**Mass, gr**	**Dimension mm**		**Mass, gr**	**Dimension mm**		**Mass, gr**	**Dimension mm**		**Mass, gr**
1	155,3	8199	1	152,35	7882	1	152,89	7975	1	151,52	7939
2	155,3	V_c, mm³	2	150,92	V_c, mm³	2	151,28	V_c, mm³	2	151,85	V_c, mm³
3	154,6	3534656	3	151,69	3462025	3	151,89	3457810	3	152,29	3487037
4	154,3	p, kg/m³	4	151,26	p, kg/m³	4	152,51	p, kg/m³	4	153,44	p, kg/m³
5	151,2	2319,6	5	152,18	2276,7	5	150,17	2306,4	5	150,46	2276,7
6	151,0	Load, kN	6	151,21	Load, kN	6	150,07	Load, kN	6	150,77	Load, kN
7	150,8	1057,7	7	151,36	1040,2	7	151,50	1023,3	7	150,63	994,8
8	150,5	$R_{15×15}$, MPa	8	152,08	$R_{15×15}$, MPa	8	151,53	$R_{15×15}$, MPa	8	150,90	$R_{15×15}$, MPa
9	151,6	45,27	9	150,99	45,24	9	150,29	44,60	9	152,11	43,35
10	150,9	A_c, mm²	10	150,17	A_c, mm²	10	150,92	A_c, mm²	10	151,47	A_c, mm²
11	151,5	23365,76	11	150,91	22992,03	11	150,17	22945,75	11	152,22	22946,32
12	150,9		12	150,23		12	151,40		12	152,06	
											$f_{m15×15}$
											44,61
									Standart deviation:		0,90

The primary objective today is to optimize the use of collected material data, taking into account the influence of sample shape and testing methods on concrete strength. This need has become the

Many reinforced concrete elements have characteristic differences, with more complex radial cross-sections, which do not correspond to the cross-section of prototype cubes. Therefore, the process of research becomes important in determining the degree to which results obtained from cube testing can be applied to real constructions. It is impossible to cover all the peculiarities of real-world structures within the context of a single study. As a result, the focus of the next section is on the transverse sections of pre-stressed elements, during the operation of which cracks were formed and developed in the compression zone of the cross-section **(Shunzhi Qianab, et al., 2019)**.

When studying the influence of shape, cross-section dimensions, and other factors on strength, as well as possible sources of error, it is reasonable to apply the theory of equilibrium conditions of mechanical systems under the action of applied forces and moments. Consequently, the next examined model demonstrates the collapse of certain concrete elements under compression.

Further below, **Table 4** presents the results of the compressive strength test of a concrete cube carried out on May 19, 2023. The data clearly show that the measured concrete strength reached 47.04 MPa, indicating a notable improvement compared to the previous series of experiments. In addition, the average hardening index was determined to be 1.28, reflecting the progressive development of the material's structural integrity over time.

Table 4
Testing of Concrete Cube for Compressive Strength Conducted on 19.05.2023 (Author's Materials)

19.05.2023											
								Age	**21**	**28.04.2023**	
Concrete Cube Compressive Strength Test											
1_cube			**2_cube**			**3_cube**			**4_cube**		
Dimension mm		**Mass, gr**	**Dimension mm**		**Mass, gr**	**Dimension mm**		**Mass, gr**	**Dimension mm**		**Mass, gr**
1	152,33	8056	1	154,30	8238	1	153,12	8030	1	150,86	8002
2	151,14	V_c, mm^3	2	154,08	V_c, mm^3	2	152,44	V_c, mm^3	2	152,73	V_c, mm^3
3	152,18	3452213	3	156,43	3536570	3	151,62	3502244	3	151,36	3472598
4	149,91	p, kg/m^3	4	157,24	p, kg/m^3	4	152,60	p, kg/m^3	4	152,52	p, kg/m^3
5	151,40	2333,6	5	150,46	2329,4	5	150,25	2292,8	5	151,67	2304,3
6	151,08	Load, kN	6	150,40	Load, kN	6	152,52	Load, kN	6	151,23	Load, kN
7	151,89	958,8	7	150,15	1133,4	7	152,36	1071	7	151,25	1063,9
8	151,47	$R_{15×15}$, MPa	8	149,73	$R_{15×15}$, MPa	8	151,80	$R_{15×15}$, MPa	8	151,02	$R_{15×15}$, MPa
9	150,12	41,82	9	151,42	48,53	9	151,51	46,30	9	151,84	46,30
10	150,80	A_c, mm^2	10	151,49	A_c, mm^2	10	152,30	A_c, mm^2	10	150,58	A_c, mm^2
11	150,25	22929,53	11	151,33	23355,64	11	150,78	23130,86	11	151,51	22976,41
12	151,06		12	151,45		12	151,05		12	150,62	
											$f_{m15×15}$
											47,04
										Standart deviation:	1,28

Comparing the results shown in **Tables 2** and **3** with those in **Table 4**, we noticed a gradual and stable increase in strength values. This improvement became especially visible after the third week of curing. Most likely, it is connected with better hydration of the cement and denser internal bonding of the mix. Such a tendency was observed for all specimen types, which confirms the reliability of the selected testing method. The tensile stresses acting within a localized zone on a single grain embedded in the natural concrete matrix can initiate minor failures of certain particles within the layer. The breakdown of these fine inclusions subsequently destabilizes the concrete structure and leads to the initiation of surface micro-cracks. It should be noted, however, that the failure of structural volumes within concrete layers does not always represent a negative factor in the overall collapse of the cross-section. Partial damage develops when the cumulative number of failed elements exceeds a critical threshold, which can be regarded as the limit state. The final stage is characterized by the fragmentation of the specimen into several parts. During this ultimate phase, the overall stress in the critical zone approaches the tensile strength of the concrete cross-section, manifested through the propagation of micro-cracks.

Thus, the series of tests on concrete cubes **Tables 1-4** revealed the patterns of strength variation in the material. To validate these findings and broaden the analysis, compressive strength tests were performed on cylindrical specimens, as presented in **Tables 5-6**.

Subsequently, concrete cylinders were tested for compressive strength, as presented in **Table 5** below. The results in **Table 5** clearly indicate that the measured concrete strength reached 41.93 MPa, while the overall hardening index was 0.69. This final experimental stage demonstrated satisfactory outcomes, showing a reliable performance of the material. Moreover, when compared with the results of previous tests presented in **Tables 2-4**, the data from **Table 5** demonstrates a consistent and progressive improvement in the evaluation of the specimens. This indicates the high effectiveness of the applied testing methodology and its reliability in conducting the experiments. The results confirm the validity and reproducibility of the approach used to assess the mechanical properties of the concrete. Furthermore, the observed trends highlight the sensitivity of the testing procedure to variations in specimen behavior, allowing for a detailed analysis of performance differences among cylindrical, cubic, and prismatic samples. These findings provide strong support for the adopted methodology as a reliable tool for experimental concrete research.

Table 5
Compressive strength test of a concrete cylinder conducted in the course of the study (Author's Materials)

Concrete Cylinder Compressive Strength Test														
1_cylinder			**2_cylinder**			**3_cylinder**			**4_cylinder**			**5_cylinder**		
Dimensin		**Mass,**	**Dimensin**		**Mass**	**Dimensin**		**Mass**	**Dimensin**		**Mass**	**Dimensin**		**Mass**
1	149,5	12025,	1	149,3	12308,0	1	149,1	12049,	1	149,7	12281,0	1	149	1230
2	149,5	V_c, mm^3	2	149,3	V_c, mm^3	2	149,3	V_c, mm^3	2	149,8	V_c, mm^3	2	149	V_c, mm^3
3	149,5	521725	3	149,6	5269849	3	149,2	51984	3	149,9	531246	3	150	5301
4	150,1	p, kg/m^3	4	149,2	p, kg/m^3	4	149,2	p, kg/m^3	4	149,7	p, kg/m^3	4	150	p, kg/m^3
5	296,1	2304,9	5	300,7	2335,6	5	297,2	2317,8	5	301,3	2311,7	5	299	2321,
6	296,5	Load, kN	6	300,7	Load, kN	6	296,8	Load, kN	6	301,1	Load, kN	6	300	Load, kN
7	296,7	729,9	7	300,6	738,9	7	297,0	722,2	7	301,4	754,5	7	299	819,9
8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa
9	-	41,48	9	-	42,17	9	-	41,27	9	-	42,79	9	-	46,36
10	-	A_c, mm^2	10	-	A_c, mm^2	10	-	A_c, mm^2	10	-	A_c, mm^2	10	-	A_c, mm^2
11	-	17596	11	-	17523,3	11	-	17499	11	-	17632,0	11	-	1768
12	-		12	-		12	-		12	-		12	-	
														41,93
													Standart deviation:	0,69

In **Table 6**, the results of the compressive strength test of a concrete cylinder conducted on 28 April 2023 are presented. The obtained compressive strength was 49.18 Mass, gr, indicating a normal hardening process. This result is higher compared to the value reported in the previous **Table 5**.

Table 6
Concrete Cylinder Compressive Strength Test Conducted on 28.04.2023 (Author's Materials)

Concrete Cylinder Compressive Strength Test														
1_cylinder			**2_cylinder**			**3_cylinder**			**4_cylinder**			**5_cylinder**		
Dimension		**Mass**	**Dimensin**		**Mass**	**Dimensin**		**Mass**	**Dimensin**		**Mass**	**Dimensin**		**Mass**
1	149,9	12332,	1	149,7	12220	1	149,2	11999,0	1	149,5	12208	1	149,8	12246
2	149,6	V_c, mm^3	2	149,6	V_c, mm^3	2	149,3	V_c, mm^3	2	149,5	V_c, mm^3	2	149,9	V_c, mm^3
3	150,3	531564	3	150,2	52725	3	149,2	5218887	3	149,5	52676	3	149,7	527684
4	150,2	p, kg/m^3	4	150,1	p, kg/m^3	4	150,1	p, kg/m^3	4	149,7	p, kg/m^3	4	149,	p, kg/m^3
5	300,7	2319,9	5	298,6	2317	5	297,4	2299,1	5	299,7	2317	5	298,9	2320,7
6	300,5	Load, kN	6	298,6	Load, kN	6	297,4	Load, kN	6	299,3	Load, kN	6	299,3	Load, kN
7	300,5	914,3	7	298,4	877,3	7	297,3	813,9	7	299,9	827,3	7	299,1	900,7
8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa	8	-	f_{cyl}, MPa
9	-	51,71	9	-	49,68	9	-	46,39	9	-	47,07	9	-	51,04
10	-	A_c, mm^2	10	-	A_c, mm^2	10	-	A_c, mm^2	10	-	A_c, mm^2	10	-	A_c, mm^2
11	-	17682,	11	-	17658	11	-	17546,2	11	-	1757	11	-	17646
12	-		12	-		12	-		12	-		12	-	
														49,18
													Standart deviation	2,37

The tests of cylindrical specimens **Tables 5-6** demonstrated consistent results in terms of compressive strength. Notably, the values obtained in the second series **Table 6** were higher than those in the previous series **Table 5**, indicating a positive trend in concrete hardening. Subsequently, experimental measurements were carried out on three prism specimens under flexural loading, and the results are presented in **Table 7**. The findings showed that the flexural strength of the concrete reached a value of 6.01, demonstrating the material's ability to withstand bending stresses.

Table 7
Flexural strength test of concrete prisms (Author's Materials)

Concrete Prism Flexural Strength Test								
1_prism			2_prism			3_prism		
Dimensions, mm		Mass, gr	Dimensions, mm		Mass, gr	Dimensions, mm		Mass, gr
1	101,83	9455	1	101,92	9348	1	100,20	9224
2	101,18	V_c, mm^3	2	100,60	V_c, mm^3	2	101,21	V_c, mm^3
3	102,94	4098783	3	100,20	4036964	3	99,89	4027077
4	100,97	p, kg/m^3	4	101,32	p, kg/m^3	4	101,63	p, kg/m^3
5	100,67	2306,8	5	102,51	2315,6	5	100,24	2290,5
6	100,05	Load, kN	6	97,74	Load, kN	6	100,62	Load, kN
7	100,97	13,55	7	100,94	14,19	7	100,11	13,09
8	101,47	f_{fl}, MPa	8	98,97	f_{fl}, MPa	8	100,44	f_{fl}, MPa
9	400,00	5,90	9	401,00	6,32	9	398,00	5,81
10	401,00	A_c, mm^2	10	402,00	A_c, mm^2	10	399,00	A_c, mm^2
11	399,00	-	11	397,00	-	11	398,00	-
12	399,00		12	398,00		12	398,50	
								6,0
							Standart deviation:	0,27

Metallic collapsible molds were used to prepare the specimens. The concrete mix was compacted using vibrators with a frequency of 2,500 semi-oscillations per minute and an amplitude of 0.45 mm.

As shown in **Table 8**, further experimental measurements were carried out on three additional concrete prisms under flexural loading. The results demonstrated that the flexural strength of the concrete reached 8.36, indicating improved performance compared with the previous series of prism tests.

Table 8
Flexural strength test of concrete prisms (Author's Materials)

Concrete Prism Flexural Strength Test								
4_prism			5_prism			6_prism		
Dimensions, mm		Mass, gr	Dimensions, mm		Mass, gr	Dimensions, mm		Mass, gr
1	101,04	9304	1	101,98	9247	1	103,29	9435
2	100,30	V_c, mm^3	2	101,68	V_c, mm^3	2	101,34	V_c, mm^3
3	101,37	4004752	3	100,44	4027835	3	101,62	4177691
4	99,03	p, kg/m^3	4	102,25	p, kg/m^3	4	104,97	p, kg/m^3
5	100,14	2323,2	5	97,29	2295,8	5	101,08	2258,4
6	98,80	Load, kN	6	99,09	Load, kN	6	101,18	Load, kN
7	100,53	19,82	7	96,66	17,68	7	102,58	19,13
8	99,52	f_{fl}, MPa	8	100,01	f_{fl}, MPa	8	103,06	f_{fl}, MPa
9	399,00	8,93	9	404,00	8,11	9	398,00	8,05
10	400,00	A_c, mm^2	10	407,00	A_c, mm^2	10	398,00	A_c, mm^2
11	400,00	-	11	404,00	-	11	400,00	-
12	400,00		12	399,00		12	398,00	
								8,36
							Standart deviation:	0,49

The results showed that the flexural strength of the concrete was 8.36.

Experimental measurements of the following three prisms in bending were carried out on April 28, 2023, the results of which are presented in **Table 8**.

Based on the experimental data from the conducted studies of cast concrete cube specimens, the results of compression tests were compiled into a comprehensive summary table presented in **Table 9**. From this data, a graph illustrating the dependence of the standard deviation of concrete compressive strength over the entire period of experimental measurements was constructed, as shown in **Figure 13.**

Table 9

Overall Experimental Data of Concrete Cube Specimens' Compressive Strength Over the Entire Measurement Period (Author's Materials)

Nr	Mix	Age, days	p, kg/m^3	f_{cyl}, MPa	$f_{c,150x150}$, MPa	Standard deviation
1	Pouring 1	7	2317	30,63	38,28	2,35
		14	2295	35,69	44,61	0,90
		21	2315	37,64	47,04	1,28
		28	2313	41,93	52,41	0,69
		153	2307	49,18	61,47	2,37

The results of compressive strength measurements using the standard destructive testing method for selected specimens exhibited significant scatter, caused both by the heterogeneity of the concrete and other factors **(Sorokina, 2018)**.

The variability in compressive strength measurements highlights the inherent heterogeneity of concrete as a composite material. Differences in aggregate distribution, cement paste consistency, and curing conditions can all contribute to the observed scatter in results, even when specimens are prepared under controlled laboratory conditions. Understanding this variability is crucial for interpreting test results and for designing concrete structures with reliable performance.

In addition to statistical evaluation, compressive strength data can be used to assess the quality and uniformity of concrete batches. By analyzing the range of measured values and calculating parameters such as the mean, standard deviation, and coefficient of variation, engineers can ensure that the produced concrete meets the required standards and specifications. This approach allows for informed decisions regarding mix adjustments, quality control, and structural safety.

A key characteristic of concrete is its compressive strength. Until recently, concrete strength was assessed primarily by its grade (denoted by the letter "M" followed by a number indicating the average compressive strength of the specimens in kgf/cm²).

Currently, the principal strength parameter of concrete defined in regulatory standards is its class, designated by the letter B and a number corresponding to the guaranteed compressive strength in megapascals (MPa). This parameter is determined with a reliability factor of 0.95, which implies that the specified strength is attained in 95% of tested specimens.

Considering the standard deviation of the actual (mean) compressive strength of the concrete specimens, with a 0.95 probability, it can be asserted that the actual (mean) compressive strength of the tested concretes falls within the range:

$$30{,}63\text{MPa} \leq R_{B}15(M200) \leq 38.28 \text{ MPa};$$
$$35{,}69 \text{ MPa} \leq R_{B}15(M200) \leq 44.61 \text{ MPa};$$
$$37{,}64 \text{ MPa} \leq R_{B}15(M200) \leq 47.04 \text{ MPa};$$
$$41{,}93 \text{ MPa} \leq R_{B}15(M200) \leq 52.41 \text{ MPa};$$
$$49{,}18 \text{ MPa} \leq R_{B}15(M200) \leq 61.47 \text{ MPa};$$

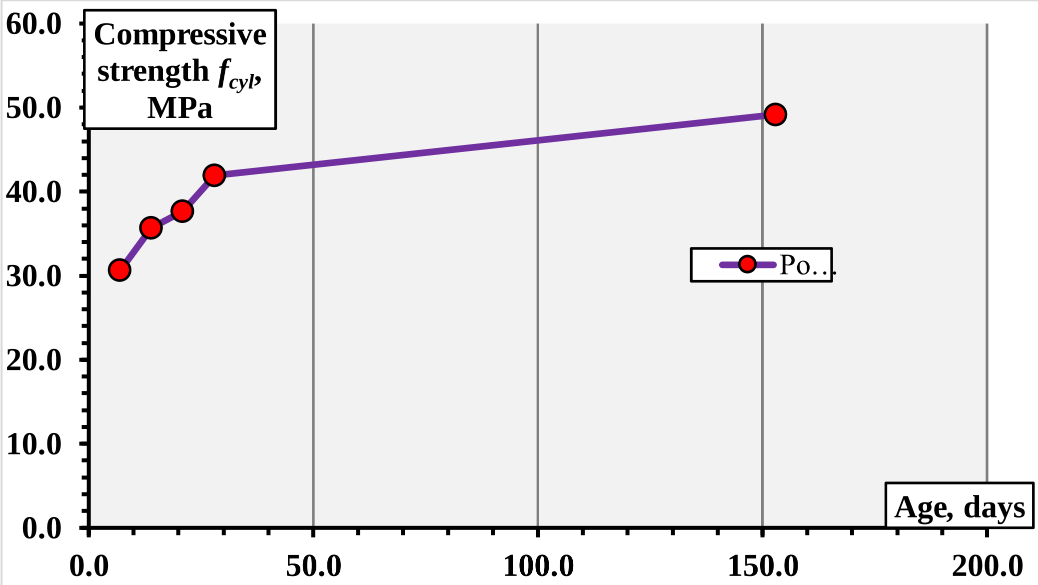

Figure 13 – Standard Deviation of Concrete Compressive Strength (Author's Materials)

The essence of the influence of the water–cement ratio on concrete strength is as follows. The amount of water added to the concrete mix always exceeds the amount required for chemical interaction with cement. This is necessary to provide the mixture with sufficient workability for dense placement. As the excess water evaporates, pores form within the concrete, which leads to a reduction in concrete density, the effective cross-sectional area of the structure, and, consequently, a decrease in strength. **Figure 13** graphically illustrates the total elapsed time after casting the concrete cubes and the effect of the water–cement ratio on compressive strength.

5 CONCLUSIONS

1. Based on the results obtained, it can be noted that non-destructive testing methods are convenient when quick evaluation is required, for example, at construction sites. Nevertheless, destructive testing remains the most accurate way to study the actual mechanical behavior of concrete under load. The experiments confirmed that the volume of the element has little influence on strength, while the increase of surface area tends to reduce it. In practice, this means that the choice of testing method should depend on the research goal and available equipment.
2. The studies demonstrated a practical absence of influence of the element's volume on its compressive strength and, consequently, on microfracture processes.
3. At the same time, increasing the surface area of an element while keeping its volume constant results in a decrease in concrete strength and a reduction in the extent of micro-crack formation. This finding is confirmed by the experimental results obtained from specimens with channels that substantially enlarge the element's surface area.
4. Based on the obtained experimental results, the coefficient of variation of the strength parameters of the specimens presented in the tables and in the diagram was determined. The specimens were produced using three different methods, with a minimum of 10 samples for each type.
5. High coefficients of variation were obtained because the experiments were performed on small-scale specimens (cubes, cylinders, and prisms). Sampling of such small elements from the concrete body results in significant variability of properties, consistent with the heterogeneous nature of concrete.
6. Using averaged properties for stress assessment can lead to significant errors in determining actual stresses. Therefore, it is necessary to determine individual characteristics for each point of the study.

REFERENCES

1. **Dem'yanenko O.V., Kopanitsa N.O., Sorokina E.A., Nichinskii A.N**. Complex modifying additives for cement construction mixes. Stroitel'nye materialy. 2019. No. 7. Pp. 16-20. https://doi.org/10.31675/1607-1859-2019-21-6-140-148 (in Russ.).
2. **Mortars for 3D printing. MATEC Web of Conferences**. 2018. Vol. 143. 02013 - https://doi.org/10.1051/matecconf/201714302013 Eco-Vector Journals Portal
3. **Sorokina, E. A., & Kopanitsa, N. O.** (2021). Analysis and evaluation of methods for determining the strength of concrete for additive technology. Vestnik of Tomsk State University of Architecture and Building. Construction, 23(2), 87-95. https://doi.org/10.31675/1607-1859-2021-23-2-87-95 (in Russ.).
4. **Dvorkin, L., Konkol, J., Marchuk, V., & Huts, A.** (2022). Effectiveness of polymer additives in concrete for 3D concrete printing using fly ash. Polymers, 14*(24),* 5467. https://doi.org/10.3390/polym14245467
5. **Kujawa, W., Olewnik-Kruszkowska, E., & Nowaczyk, J.** (2021). Concrete strengthening by introducing polymer-based additives into the cement matrix-A mini review. Materials, 14(20), 6071. https://doi.org/10.3390/ma14206071
6. **Chahar, A. S., & Pal, P.** (2023). A review on various aspects of high-performance concrete. Innovative Infrastructure Solutions, 6, Article 6. https://doi.org/10.1007/s41062-023-01144-3
7. **O’Flaherty, F. J., Khalaf, F. J., & Starinieri, V.** (2023). Influence of additives on strength enhancement and greenhouse gas emissions of pre-cast lime-based construction products. Low-Carbon Materials & Green Construction, 1, 26. https://doi.org/10.1007/s44242-023-00026-2
8. **Mohammed, H. M. O., Hamid, R., Sheikh Abdullah, S. R., & Tan Kofli, N**. (2019). Physical and mechanical properties of high-performance concrete with alum sludge as partial cement replacement. Jurnal Teknologi (Sciences & Engineering), 65, Article 2198. https://doi.org/10.11113/jt.v65.2198
9. **Akhmetov, D., Urumbaeva, A., Tkach, E., & Sarsenova, G**. (2024). Effect of microdispersed and volumetric fiber reinforcement on the strength and durability of self-compacting concrete. Architecture and Civil Engineering, 1(4), 20-26. Retrieved from https://ace.journal.satbayev.university/index.php/journal/article/view/1265
10. **Lukpanov, R., Zharassov, S., Mkilima, T., & Aldungarova, A.** (2021). Performance of maturity method for estimation of concrete strength based on cubic specimens. Technobius, 1(4), 0008. https://doi.org/10.54355/tbus/1.4.2021.0008 (in Russ.).
11. **Anop, D., Rudenko, O., Shevlyakov, V., Aubakirova, Z., Soshnikov, N., & Begentayev, M**. (2025). Prediction of compressive strength and density of aerated ash concrete. Technobius, 5(1), 0074. https://doi.org/10.54355/tbus/5.1.2025.0074 (in Russ.).
12. **Abed, M. A., Anagreh, A., Tošić, N., Alkhabbaz, O., Alshwaiki, M. E., & Černý, R.** (2022). Structural performance of lightweight aggregate concrete reinforced by glass or basalt fiber reinforced polymer bars. Polymers, 14(11), Article 2142. https://doi.org/10.3390/polym14112142
13. **Idrees, M., Akbar, A., Saeed, F., Saleem, H., Hussian, T., & Vatin, N. I.** (2022). Improvement in durability and mechanical performance of concrete exposed to aggressive environments by using polymer. Materials, 15(11), Article 3751. https://doi.org/10.3390/ma15113751
14. **Martina, N., Bakti, R. N., Hasan, M. F. R., Maha Agung, P. A., & Setiawan, Y.** (2022). Compressive strength of concrete using lightweight brick waste as substitute for fine aggregate. International Journal of GEOMATE, 98, 189-196. https://doi.org/10.21660/2022.98.3565
15. **Siyahi, M.** (2024). Enhancing concrete prism strength using external confining pressure. Engineering Research Journal (Shoubra), 54*(1),* 23-34. https://doi.org/10.21608/erjsh.2024.330454.1370