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STUDY OF FIRE RESISTANCE OF REINFORCED CONCRETE BARS ACCORDING TO SPECIFIED CONCRETE STRENGTH INDICATORS

The article presents the results of determining the limit of fire resistance of reinforced concrete crossbars, taking into account the study of identification of strength characteristics of concrete based on the results of fire tests.

During the fire tests, two serial reinforced concrete crossbars with the same structural parameters were investigated. The experimental setup made it possible to study full-size elements. The preparation, method of conducting and obtained results of fire tests are described in detail in the previous article. During the fire tests, temperature indicators were obtained at the control points of the cross-section of the tested elements and the value of their maximum deflection depending on the test time.

The purpose of this article is based on determining the time of onset of the limit state as a sign of the loss of load-bearing capacity of reinforced concrete crossbars according to the specified concrete strength indicators, calculated based on the results of fire tests.

Based on the obtained experimental temperature indicators, temperature interpolation was carried out and temperature distributions in the cross-sections of reinforced concrete crossbars were constructed. The obtained results are adequate, since the F criterion does not exceed the table values and is equal to 0.734.

To clarify the strength properties of concrete, a deformation model was used, which is based on the use of equilibrium systems of internal layers in the section. The mathematical apparatus presented in the work allows rewriting the deformation model into a system of linear algebraic equations, the unknowns of which are the concrete strength reduction coefficients.

Based on the value of the maximum deflection of the crossbars, the problem of strength was solved and the limit of fire resistance was determined according to the specified coefficients of concrete strength reduction. It is shown that the onset of the limit state due to the loss of bearing capacity is not reached in all cases and is determined according to the technical conditions (approximately 0.3 of the destructive load) M = 50 кНм.

***Key words:** fire resistance, reinforced concrete, crossbar, test, strength, temperature, calculation.*

Problem setting. A large share in the field of construction falls on the use of reinforced concrete structures. Various factors affect the reliability of these building structures in fire conditions, in particular, allowed deviations from the project during construction, changes in the structural scheme of the element, deformations obtained during operation, the stress-deformed state of the structure in fire conditions, the strength of construction materials, etc.

In fire conditions, the greatest danger is the destruction of bent elements of reinforced concrete structures, namely reinforced concrete crossbars and beams. These building structures have the largest dimensions and carry a large load, as they overlapping of floors and covering of roofs of buildings.

To ensure the compliance of reinforced concrete crossbars with the purpose and their ability to maintain the necessary operational qualities in fire conditions, an effective way is to ensure a standardized limit of fire resistance. The reliability of these building structures in fire conditions depends on the strength characteristics of concrete. At the current stage, the strength characteristics of concrete need to be clarified by conducting fire tests in order to increase the reliability of the data, which will allow obtaining more accurate calculation results when determining the fire resistance limit of reinforced concrete structures of this type.

Analysis of recent research and publications. Experimental and computational studies are used to ensure the normalized limit of fire resistance of reinforced concrete crossbars under fire conditions [1]. Experimental research is based on conducting fire tests, which are conducted in accordance with standards [2, 3]. However, experimental studies of determining the limit of fire resistance of reinforced concrete crossbars cannot always be correctly applied. Since during fire tests it is impossible to reproduce the full compliance with the conditions of fastening and loading of the tested element.

Calculation studies are based on various mathematical models, among which there are models that take into account all the features of the behavior of reinforced concrete under the conditions of the thermoforce effect of fire. However, the obtained calculation results need to be carefully checked, since a set of properties of reinforced concrete components is used as the initial data, which can differ significantly within the same class of material [4].

The strength characteristics of concrete given in DSTU-NB EN 1992-1-2:2012 Eurocode 2 [5] are used as initial data for calculation studies to determine the limit of fire resistance of reinforced concrete building structures. The disadvantage is that the strength characteristics of reinforced concrete are not determined, but their universal values are used, in accordance with this standard. The values of the concrete strength reduction coefficients depending on the time of fire exposure obtained by laboratory tests of small cube samples do not reproduce the performance of concrete in full-size building structures under the influence of high temperatures, which is the reason for the appearance of significant errors [5].

To obtain reliable results regarding the determination of the limit of fire resistance of reinforced concrete crossbars, the method of fire tests with mathematical processing of the results is used, which provides flexibility when taking into account the boundary conditions for reinforced concrete elements [4, 6]. This method of conducting research involves the application of any level of load, using different theories of the strength of materials, the use of various geometric parameters of structures, and clarification of the strength characteristics of materials that are components of reinforced concrete according to the measurements obtained during fire tests [7, 8].

Formulation of the goals of the article. The goals of the article is to determine the limit of fire resistance of reinforced concrete crossbars by calculation using the strength characteristics of concrete identified by the results of fire tests, which are described in the work [2]. To achieve the goal of the article, it is necessary to complete the following tasks:

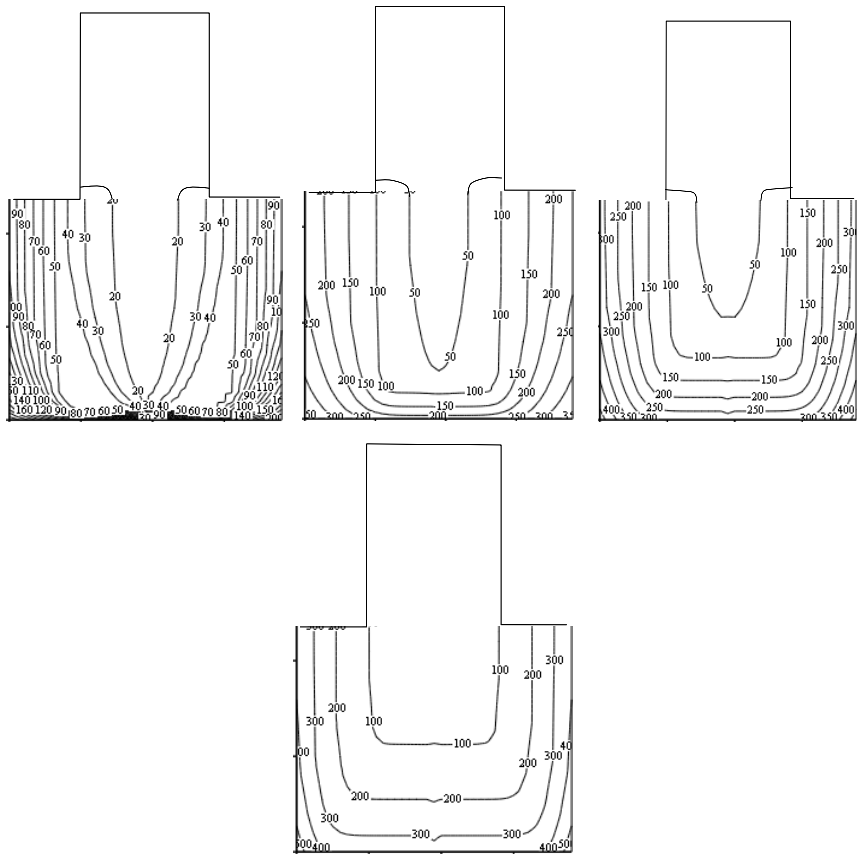
1. To obtain temperature distributions by interpolation of temperatures determined during fire tests and to plot graphs in the form of isotherms in order to analyse the obtained results.

2. Using the mathematical apparatus described in works [4, 9], specify the strength coefficients of concrete using the initial data obtained from the results of fire tests.

3. To determine by calculation the fire resistance limit of reinforced concrete crossbars using concrete deformation diagrams built according to specified concrete strength indicators.

Presentation of the main research material. To determine the limit of fire resistance of reinforced concrete crossbars by calculation using the characteristics of concrete strength, specified by the results of fire tests, the results of experimental studies specified in the work [2] were used. In the work, reinforced concrete crossbars of the tau type were investigated. The method of carrying out, the structural scheme of two twin samples and the obtained results of fire tests are given in [2]. The analysis of the described results showed that with the same position of the thermocouples, the graphs of the temperature dependences at the control points of the furnace chamber and the temperature dependences at the control points of the inner layers of the reinforced concrete crossbars-samples from the test time are similar, which confirms the good reproducibility of the experiment. The advantage of this test is that the experimental setup made it possible to investigate serial full-size crossbars.

Based on the temperature indicators obtained during the fire tests, interpolation was carried out according to the block diagram described in [9] and the temperature distributions shown in the figure were obtained 1.



a *b* *c* *d*

Figure 1 – Temperature distributions in a reinforced concrete crossbar (°C): *a* – 15 min; *b* – 30 min; *c* – 45 min; *d* – 60 min

Isotherms in fig. 1 show that the results obtained by interpolation are adequate. The analysis of statistical parameters confirmed the adequacy of the temperature interpolation results, because the calculated Fisher's criterion is 0.734 and does not exceed the table value equal to 1.01 [2].

A necessary component of determining the limit of fire resistance is the identification of the strength characteristics of concrete. To clarify the strength characteristics of concrete, the deformation indicators of reinforced concrete crossbars during fire tests, which are described in the work [4], were taken and analysed. Figure 2 shows the dependences of the largest deflection of the tested samples.

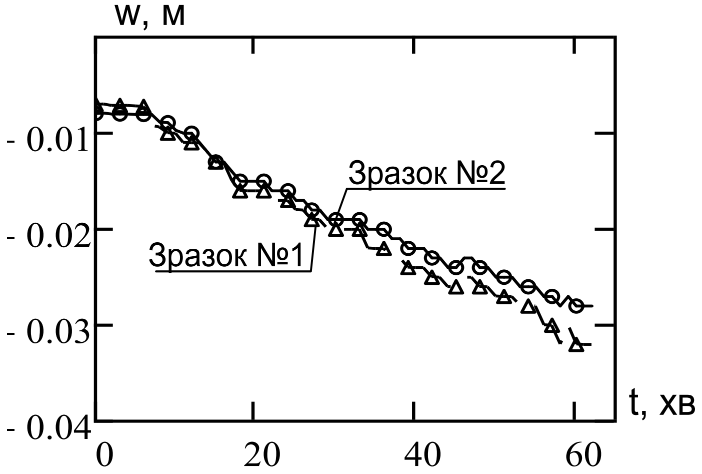


Figure 2 – Dependence of the largest deflection of reinforced concrete crossbars

The plotted curves of the maximum deflection of reinforced concrete crossbars show that the fire resistance limit is not reached, since the rate of increase and the maximum deflection do not exceed the permissible values (D =35 mm, d/dt =1.54 mm/min).

Using the obtained data on the interpolation of temperatures in the sections of reinforced concrete cross-sections, the data on the maximum deflection of the cross-bar and the mathematical apparatus given in [9], the coefficients of reduction of concrete strength from the temperature of reinforced concrete cross-bars subjected to fire tests were identified by solving a system of linear algebraic equations, the dependence graphs of which are shown in fig. 1.

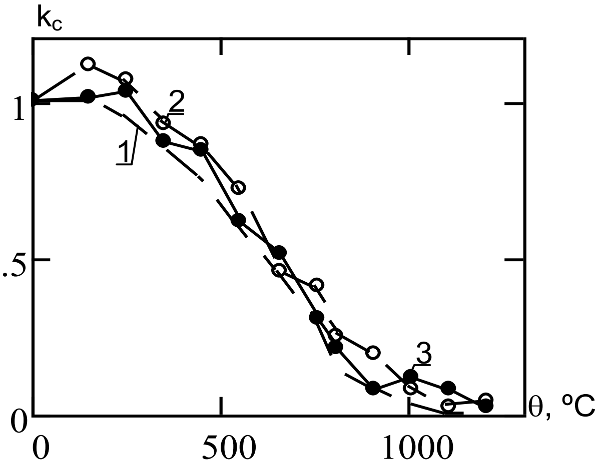


Figure 3 – Dependencies of the concrete strength reduction factor: 1 – standard dependence, 2 – dependence for sample № 1, 3 – dependence for the sample № 2

Taking into account the obtained refined dependence of the coefficient of reduction of concrete strength on temperature for calculating the fire resistance of reinforced concrete crossbars, appropriate concrete deformation diagrams were constructed. The constructed diagrams are shown in fig. 4.

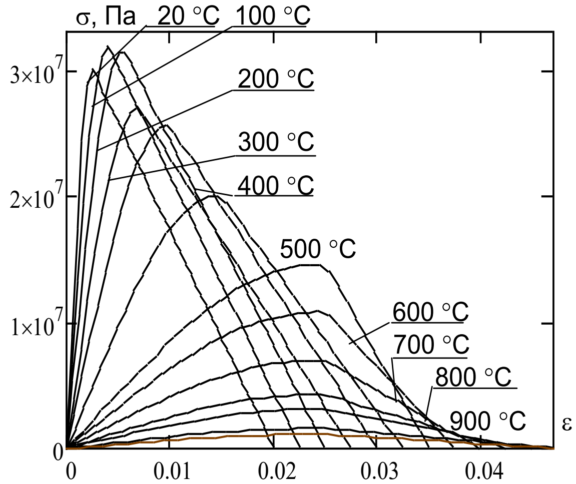


Figure 4 – Diagrams of concrete deformation

Based on the results of the research, the problem of strength was solved based on the value of the maximum deflection of the reinforced concrete crossbar. The cross-section of the crossbar was divided into rectangular zones of size 10×10 mm.

The limit maximum deflection of the crossbar is:

$$D = \frac{L^2}{400 \cdot b} = \frac{2{,}56^2}{400 \cdot 0{,}95} = 0{,}036 \text{ м} \quad (1)$$

The limit curvature of the crossbar is:

$$\chi = 24 \cdot 10^{-3} 0{,}95^{-1} = 0{,}0053 \text{ m}^{-1} \quad (2)$$

At each control point in time, the moment of reaching the critical curvature of the crossbar is determined according to the formula given in works [2, 9].

In fig. 5 graphs of the dependence of the internal moment on the curvature of the crossbar are plotted for some moments of the test time.

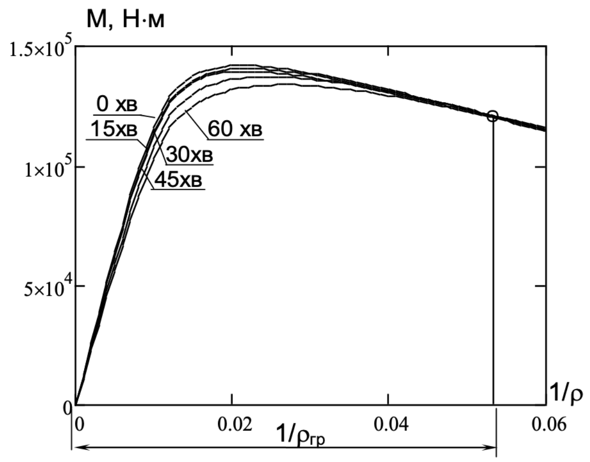


Figure 5 – Graphs of the moment at the limit value of the curvature for the specified moments of the test of the reinforced concrete crossbar

As a result of the performed calculation, the dependences of the reduction of the load-bearing capacity on the time of the tests for the two studied crossbars were determined. The resulting dependencies are shown in Fig. 6.

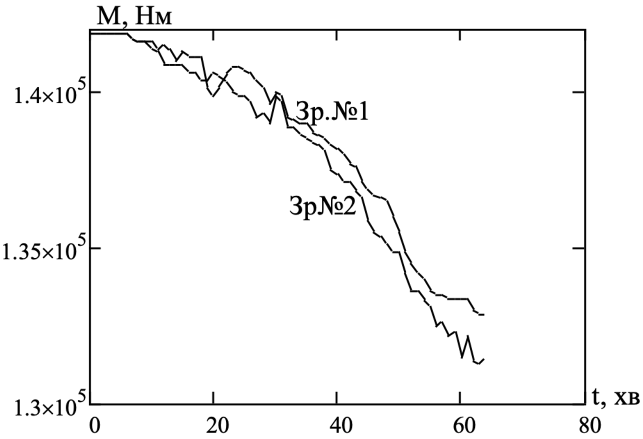


Figure 6 – Graph of reduction of the load-bearing capacity of a reinforced concrete crossbar according to the values obtained by identifying the strength characteristics of concrete

The obtained calculations showed that the time of onset of the limit state due to the loss of bearing capacity is not reached in all cases. The time of occurrence of the limit state was recognized in view of the selected acting moment in this crossbar, according to the technical conditions (approximately 0.3 of the destructive load) M = 50 kN·m.

Conclusions. In view of the conducted studies of fire resistance of reinforced concrete crossbars, the following conclusions were formed by calculation using the specified strength characteristics of concrete:

1. Temperature distributions were obtained by interpolation of temperatures determined during fire tests. The obtained results are adequate, since the F criterion is equal to 0.734.

2. Refined concrete strength reduction coefficients were determined by solving a system of algebraic equations using the initial data obtained during fire tests described in the work [4].

3. It was established that the maximum deflection of the tested crossbar does not exceed the permissible values and is equal to 36 mm.

4. As a result of the calculation, it was established that the time of onset of the limit state due to the loss of bearing capacity is not reached and is determined according to the technical conditions (approximately 0.3 of the destructive load) M = 50 kN·m.

REFERENCES

1. Analysis and prediction methods for the static properties of reinforced concrete crossbar s under fire / C. Liu, B. Zhou, X. Guo, C. Liu, L. Wang *// Structures.* – 2023. – Vol. 47. – P. 2319–2330. – https://doi.org/10.1016/j.istruc.2022.12.041

2. Fedchenko S. M. Improvement of the method of calculating the fire resistance of reinforced concrete beams and crossbars:. Doctor of Philosophy Dissertation in the field of fire safety. 2024, p. 198. https://chipb.dsns.gov.ua/upload/1/9/9/8/0/9/7/fedcenko-sm-disertaciia-na-temu-udoskonalennia-metodu-rozraxunku-na-vognestiikist-zalizobetonnix-balok-ta-rigeliv.pdf

3. DSTU EN 1363-1:2023 Fire resistance test. Part 1. General requirements (EN 1363-1:2020, IDT) [Valid from 2024-03-01].

4. DSTU EN 1365-3:2023 Testing load-bearing building structures for fire resistance. Part 3. Crossbars. (EN 1365-3:1999, IDT), [Valid from 2024-05-01].

5. DSTU-H B EN 1992-1-2:2012 Eurocode 2. Design of reinforced concrete structures. Part 2. General provisions. Calculation of structures for fire resistance (EN 1992-1-2:2004, IDT) : DSTU (State Standard of Ukraine). Decree from 21.12.2012 № 652 On the adoption of national standards identical to European regulatory documents for the design of building structures.

6. Nuianzin O. Study of the thermal effect of fire on a reinforced concrete crossbar based on the results of experimental tests *// Emergency situations: prevention and elimination.* – 2022. – V. 6. – №. 1. – p. 75-84. https://fire-journal.ck.ua/index.php/fire/article/view/122

7. Kodur V. Comparative fire behavior of reinforced concrete beams made of different concrete strengths / V. Kodur, S. Banerji // Proceedings of the 11th International Conference on Structures in Fire (SiF2020), Brisbane (Australia), 30 November – 2 December, 2020 yr. – Brisbane (Australia): The University of Queensland, 2020. – P. 254–261. – https://doi.org/10.14264/bd10594

8. Veselivskyi R. B. Justification of the method of bringing the limit of fire resistance obtained during fire tests to the limit of fire resistance according to the standard fire temperature regime / R. B. Veselivskyi // *Scientific bulletin: Civil protection and fire safety,* 2021. – 1 (11), 56–63. https://doi.org/10.33269/nvcz.2021.1(11).56-63

9. Fedchenko S. M. Study of reduction of strength of reinforced concrete crossbar during fire tests. *Communal economy of the cities*, 2023. – *6* (180), 176–186. https://doi.org/10.33042/2522-1809-2023-6-180-176-186

ПЕРЕЛІК ПОСИЛАНЬ

1. Analysis and prediction methods for the static properties of reinforced concrete beams under fire / C. Liu, B. Zhou, X. Guo, C. Liu, L. Wang *// Structures.* – 2023. – Vol. 47. – P. 2319–2330. – https://doi.org/10.1016/j.istruc.2022.12.041

2. Федченко С. М. Удосконалення методу розрахунку на вогнестійкість залізобетонних балок та ригелів: дис. доктора філософії за спеціальністю – пожежна безпека. Черкаси. 2024, С. 198. https://chipb.dsns.gov.ua/upload/1/9/9/8/0/9/7/fedcenko-sm-disertaciia-na-temu-udoskonalennia-metodu-rozraxunku-na-vognestiikist-zalizobetonnix-balok-ta-rigeliv.pdf

3. ДСТУ EN 1363-1:2023 Випробування на вогнестійкість. Частина 1. Загальні вимоги (EN 1363-1:2020, IDT) [Чинний від 2024-03-01].

4. ДСТУ EN 1365-3:2023 Випробування несучих будівельних конструкцій на вогнестійкість. Частина 3. Балки. (EN 1365-3:1999, IDT), [Чинний від 2024-05-01].

5. ДСТУ-Н Б EN 1992-1-2:2012 Єврокод 2. Проектування залізобетонних конструкцій. Частина 2. Загальні положення. Розрахунок конструкцій на вогнестійкість (EN 1992-1-2:2004, IDT) : ДСТУ (Держ. Стандарт України). Наказ від 21.12.2012 № 652 Про прийняття національних стандартів, ідентичних до європейських нормативних документів на проектування будівельних конструкцій.

6. Нуянзін О. Дослідження теплового впливу пожежі на залізобетонну балку за результатами експериментальних випробувань *// Надзвичайні ситуації:*

попередження та ліквідація. – 2022. – Т. 6. – №. 1. – С. 75-84. https://fire-journal.ck.ua/index.php/fire/article/view/122

7. Kodur V. Comparative fire behavior of reinforced concrete beams made of different concrete strengths / V. Kodur, S. Banerji // Proceedings of the 11th International Conference on Structures in Fire (SiF2020), Brisbane (Australia), 30 November – 2 December, 2020 yr. – Brisbane (Australia): The University of Queensland, 2020. – P. 254–261. – https://doi.org/10.14264/bd10594

8. Веселівський Р. Б. Обґрунтування методу приведення межі вогнестійкості отриманої під час вогневих випробувань до межі вогнестійкості за стандартним температурним режимом пожежі / Р. Б. Веселівський // *Науковий вісник: Цивільний захист і пожежна безпека,* 2021. – 1 (11), 56–63. https://doi.org/10.33269/nvcz.2021.1(11).56-63

9. Федченко С. М. Дослідження зниження міцності залізобетонної балки при вогневих випробуваннях. *Комунальне господарство міст*, 2023. – *6* (180), 176–186. https://doi.org/10.33042/2522-1809-2023-6-180-176-186

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ДОСЛІДЖЕННЯ ВОГНЕСТІЙКІСТЬ ЗАЛІЗОБЕТОННИХ РИГЕЛІВ ЗА УТОЧНЕНИМИ ПОКАЗНИКАМИ МІЦНОСТІ БЕТОНУ

У статті викладені результати визначення межі вогнестійкості залізобетонних ригелів враховуючи дослідження ідентифікації міцнісних характеристик бетону за результатами вогневих випробувань.

При вогневих випробуваннях досліджувалися два серійні залізобетонні ригелі з однаковими конструктивними параметрами. Експериментальна установка дала можливість дослідити повно розмірні елементи. Підготовка, методика проведення та отримані результати вогневих випробувань детально описані у попередній статті. В ході вогневих випробувань були отримані показники температури у контрольних точках перерізу досліджуваних елементів та значення їх максимального прогину у залежності від часу випробування.

Мета даної статті ґрунтується на визначенні часу настання граничного стану за ознакою втрати несучої здатності залізобетонних ригелів за уточненими показниками міцності бетону, що розраховані за результатами вогневих випробувань.

За отриманими експериментальними показниками температури була проведена інтерполяція температури та побудовані температурні розподіли у перерізах залізобетонних ригелів. Отримані результати є адекватними, оскільки критерій F не перевищує табличних значень та дорівнює 0,734.

Для уточнення міцнісних властивостей бетону використано деформаційну модель, що заснована на використанні систем рівноваги внутрішніх шарів у *перерізі. Математичний апарат, що наведений у роботі дозволяє переписати деформаційну модель у систему лінійних алгебраїчних рівнянь, невідомими якої є коефіцієнти зниження міцності бетону.*

На основі значення максимального прогину ригелів розв'язано задачу міцності та визначено межу вогнестійкості за уточненими коефіцієнтами зниження міцності бетону. Показано, що настання граничного стану за ознакою втрати несучої здатності у всіх випадках не досягається та визначений згідно із технічними умовами (приблизно 0,3 від руйнівного навантаження) М = 50 кНм.

Ключові слова: *вогнестійкість, залізобетон, ригель, випробування, міцність, температура, розрахунок.*