DBN Concrete and reinforced concrete structures intended to operate under elevated and high temperatures

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Abstract. Current codes and regulations are applied to the design of concrete and reinforced concrete structures intended to operate under conditions of systematic exposure to elevated and high technological temperatures. It is proposed to develop a statutory instrument to replace the SNiP 2.03.04-84 changing its status for the DBN one. The purpose of the project is to create a new national regulatory instrument, which is based on the modern achievements of science, machinery and technology, advanced domestic and foreign experience of design and construction and at the same time uses theoretical and experimental studies of the updated version of SNIP 2.03.04-84. This regulatory instrument is extremely necessary for the development of national production of Ukraine. The calculation of “Concrete and Reinforced Concrete Structures for High and High Temperature Exposure” begins with the definition using Eurocode 2 EN 1992-1-1:2005 at normal temperature of 20°C, then is followed by improvements using a mathematical model of the ratio "stress-strain" of concrete at elevated temperatures, refinement of the load-bearing criteria of concrete structures in EN 1994-1-2:2004. The determination of the maximum strain on the basis of the energy approach allowed us to formulate its adjusted dependence on temperature, the values of the parameters of the stress-strain diagram. According to these data, the stress-strain diagrams of concrete during compression and heating according to Eurocode EN 1992-1-2:2004 are calculated using the formulae of the first stage.

1. Introduction

The practical implementation of scientific and methodological support is connected with the peculiarities of harmonization of national standards with Eurocodes. SNiP 2.03.04-84¹ standards were checked on according to the statutory order of the Ministry of Regional Development, Construction and Housing and Utilities Sector of Ukraine. These rules and regulations are applied to the design of concrete and reinforced concrete structures intended to operate under conditions of systematic exposure to elevated and high technological temperatures. It is proposed to develop a statutory instrument to replace the SNiP 2.03.04-84¹ with the change of status in the DBN. The purpose of the project is to create a new national regulatory instrument, which is based on the modern achievements of science, machinery and technology, advanced domestic and foreign experience of design and construction, and at the same time uses theoretical and experimental studies of the updated version of SNIP 2.03.04-84. This regulatory instrument is extremely necessary for the development of national production of Ukraine.

Nowadays, at the request of the Ministry of Regional Construction of Ukraine, the DN DNIBK with the participation of Kharkiv National University of Civil Engineering and Architecture CNUB
has developed national standards for the design of building structures, which are harmonized with the European standards of Group A (Eurocodes).

On June 1, 2011, SNiP 2.03.01-84 were cancelled and state building codes of Ukraine DBN V.2.6-98:2009 “Design of buildings and structures Concrete and reinforced concrete structures. Basic Provisions”, and the national standards of Ukraine DSTU B V.2.6-156:2010 "Design of buildings and structures. Concrete and reinforced concrete structures made of heavy concrete. Design rules” were developed, issued and put into practice in Ukraine. The latter entered into force on June 1, 2011. Both documents are harmonized with EN 1992-1-1:2005 Eurocode 2: Design of reinforced concrete structures - Part 1-1: General rules and regulations for structures with the level of conformity of "MOD". The new regulations have significant differences. First, this is a new concept of calculation: a nonlinear deformation model, second, new approaches to the assessment of reliability, loads and impacts, new principles of alternative analysis of stress-strain state of structural elements, methods of construction, new terms, symbols, designations and many others.

2. Analysis of recent research
Industrial structures of heavy concrete of average density from 2200 to 2500 kg/m$^3$, operating under conditions of exposure to elevated temperatures and humidity of the environment are heated in the range from 50 to 200°C; during the production they are heated over 200 to 1200-1400 °C.

Heat-resistant concrete in the elements of thermal units is used in accordance with Annex A SP 52-110-2009, which includes the industries of metallurgy (blast furnaces, air heaters, cast iron melting furnaces, coke oven batteries, etc.), non-ferrous metallurgy (graphite furnaces, fluidized bed furnaces), aluminium and magnesium electrolyzers, thermal, heating, burning furnaces, etc.), the oil-refining and petrochemical industries (tubular furnaces, vertical section furnaces, etc.), in the building materials industry and in other various branches.

3. General problem statement and its relation to important scientific and practical objectives
As it was shown in paragraph 1 above, the regulatory framework of Ukraine has been changed to European standards. The process of harmonization with the Eurocodes has been completed, new national regulatory documents of the State DBN and DSTU, which replaced the SNiP have been developed and put into practice. At the same time, a large section of “Concrete and Reinforced Concrete Structures Intended to Work under Elevated and High Temperatures” turned out to be omitted in the Eurocodes. Building standards and SNiP regulations were developed for this section.

SNiP standards including SNiP 2.03.04-84 were checked on according to the statutory order No. 93 (with changes made by the order of the Ministry of Regional Development of September 20, 2016 No. 256) of the Ministry of Regional Development, Construction and Housing and Utilities Sector of Ukraine dated April 18, 2016. These rules and regulations are applied to the design of concrete and reinforced concrete structures intended to operate under conditions of systematic exposure to elevated (from 50 to 200 °C inclusive) and high (above 200 °C) process temperatures.

4. Conclusion and submitted decision on SNiP 2.03.04-84
According to the results of the checking SNiP 2.03.04-84 “Concrete and reinforced concrete structures designed to operate under conditions of elevated and high temperatures” and being guided by the requirements of DSTU B A.1.1-91:2008, according to which building standards should be based on modern scientific achievements, machinery and technologies, good domestic and foreign experience of design and construction and taking into account the requirements of national, international and transnational regulatory documents, normative legislative instruments, to which Ukraine has joined, it was proposed as follows:

- to develop a regulatory instrument to replace the SNiP 2.03.04-84 changing its status for the DBN one in order to provide for the national statutory framework a statutory instrument of the national level, which will regulate the requirements for the design of concrete and reinforced concrete structures that are exposed to elevated and high temperatures;
- in accordance with the DBNA.1.1-1-93 to classify to the complex of statutory documents B.2.6 “Design of buildings and structures” and refer to the classification groups: “Fire resistance of building materials and elements” (code UKND 13.220.50), “Technical aspects” (UKND code 91.010.30) and “Concrete and reinforced concrete structures” (UKND code 91.080.40) according to DK 004.

The proposed name of the regulatory instrument is “Concrete and reinforced concrete structures designed to work under the impact of elevated and high temperatures”.

5. Analysis of recent research
Currently, the work has been done to update the regulatory framework in this area, a section with a deformation model appeared in SP 52-101-2003, but it is far from being sufficient for a proper analysis. Heat-resistant concrete in the elements of thermal units is applied in accordance with Annex A of SP 52-110-2009.

When developing a regulatory instrument to replace SNiP 2.03.04-84* changing its status for the DBN one, it is advisable to use rules and regulations SP 27.13330.2011 Concrete and reinforced concrete structures intended for use in conditions of elevated and high temperatures.

This set of rules is based on numerous theoretical and experimental studies of K.D. Nekrasov [1], V.I. Belsky [2], A.B. Toturbiyev [3], G.F. Gitman, T.N. Malkina [4], A.F. Milovanov [5], A.E. Desov [6], R. von der Hayden, P. Fritsch, R. Krischanitsa, R. Rample [7] and others.

A set of rules was developed by Gvozdev A.A. Research Institute for Reinforced Concrete - Institute of OJSC “Scientific Research Centre “Construction”: Head - Dr. of Sci. Eng. prof. A.F. Milovanov Developers: Dr. of Sci. Eng. prof. A.P. Krichevsky, S.L. Fomin; Candidates of Technical Sciences V.N. Goryachev, N.P. Zhdanova, I.M. Zaslavsky, V.N. Milonov, V.G. Petrov-Denisov, V.N. Samoilenko, V.V. Solomonov, I.S. Kuznetsova, engineers E.M. Khvoryh, V.A. Tarasova, with participation of UralNDIbud Ltd. (Candidate of Technical Sciences R.Ya. Akhtyamov) [8].

6. Aim and objectives of the research
The aim of the project is to create a new national standard DBN "Concrete and reinforced concrete structures designed to work under the impact of elevated and high temperatures", which is based on the modern achievements of science, machinery and technology, advanced domestic and foreign experience of design and construction and takes into account the requirements of national, international and transnational regulations while using theoretical and experimental studies of the updated version of SNiP 2.03.04-84* [8].

7. Materials for concrete and reinforced concrete structures
For concrete and reinforced concrete structures intended for use in elevated and high temperatures, the following should be stipulated:

- ordinary concrete is structural heavy concrete of average density from 2200 up to 2500 kg/m³;
- heat-resistant structural and thermal insulation concrete of dense structure with an average density of 900 kg/m³ and more, the compositions of which are given in Table 5.1 (No. of concrete composition, concrete class as for maximum permissible temperature of application. Starting materials are binder, hardener, milling additive, aggregates. The highest compression strength class concrete. Average concrete density, kg/m³).

Heat-resistant concrete of medium density up to 1100 kg/m³ inclusive should be provided mainly for load-bearing enclosure structures and as thermal insulation materials.

Heat resistant concrete of average density greater than 1100 kg/m³ should be provided for load-bearing structures.

When designing concrete and reinforced concrete structures operating at elevated and high temperatures, depending on their purpose and operating conditions, the quality indicators of concrete should be set, the main of them are classes of concrete according to compressive strength:

-ordinary concrete of compositions No. 1 and No. 1а according to Table 5.1 - from B20 to B60;
- heat-resistant concrete compositions according to Table 5.1;
- No. 2, 3, 6, 7 – from B15 to B50;
- No. 10, 11, 21 – from B15 to B40;
- No. 19, 20 – from B15 to B35;
- No. 12, 13, 14, 15 – from B12,5 to B25;
- No. 4, 5, 8, 9, 16–18, 23, 29 – from B12,5 to B20;
- No. 24, 27, 30 – from B2 to B10;
- No. 22, 24, 30, 32, 35–37 – from B1 to B5;
- No. 25, 28, 31, 32, 34 – from B1 to B3,5;
- No. 26, 33 – from B1 to B2,5.

It is recommended to take a concrete class with compressive strength of at least B12.5 for reinforced concrete structures made of heat-resistant concrete, operating at high temperatures.

Concrete class and grade are the main factors that characterize its strength. The concrete class is denoted by the letter B and the number. The number indicates the pressure that this class of concrete (e.g. B20 - 20 mega pascals (MPa) will withstand. The grade is denoted by the letter "M" and measured in kg/cm² from 50 to 1000 kg/cm².

The new regulations have significant differences. First, this is a new concept of calculation, a nonlinear deformation model, and second, new approaches to the assessment of reliability, loads and impacts, methods of construction.

The calculation of concrete and reinforced concrete structures intended for exposure to elevated and high temperature begins with the definition using Eurocode 2 EN 1992-1-1:2005 at normal temperature of 20°C, then is followed by improvements using a mathematical model of the ratio "stress-strain" of concrete at elevated temperatures, refinement of the load-bearing criteria of concrete structures in EN 1994-1-2:2004.

Determining the maximum strain of concrete at elevated temperatures. The essence of the method of determining the limit deformability of structurally heterogeneous construction materials is to develop the dependence of the load potential on the magnitude of the acting force \( P - \Delta l \), which are determined on the basis of equally weighted strain diagrams. Dependences of the relative load potential on the compressive force \( W - P \) were determined according to the complete diagrams of compressed concrete using the mathematical model.

![Figure 1. Diagrams \( \sigma_c - \varepsilon_c \) at the heating temperature of 20°C, 100°C, 200°C, 300°C, 400°C, 500°C, 600°C.](image)

The valid limit deformations \( \varepsilon_{cu,\theta} \) are determined on the basis of the energy approach that has already been successfully applied to similar studies.

The essence of the method of determining the ultimate deformability of structurally heterogeneous construction materials with respect to the complete diagrams \( \sigma_c - \varepsilon_c \) is in developing the dependences of the load potential on the magnitude of the acting force, which are determined on the basis of equally weighted strain diagrams. The term “load potential” or force application to movement at this stage of
loading is adopted according to [9, 10]. According to the complete diagrams of compressed concrete reordered in non-dimensional coordinates “$f_c/f_{ck}$ - $\varepsilon_c$" from diagrams ENV 1992-1-2 (Figure 3), the dependences of the relative load potential on the compressive force “$W$–$P$" were obtained. The values of the relative load potential are given in the form:

$$W = \frac{P \cdot \varepsilon \cdot l}{P_{f_c,\theta} \cdot \varepsilon_{f_c,\theta} \cdot l}.$$  \hspace{1cm} (1)$$

where $P$, $\varepsilon$ are current values of load and strains, $P_{f_c,\theta}$, $\varepsilon_{f_c,\theta}$ are values of load and strains corresponding to the maximum of the curve “$\sigma_c$–$\varepsilon_c$”.

We can get the formula of the relative potential of the load through voltage by dividing the values of $P$ and $P_{f_c,\theta}$ in the numerator and denominator of equation (2) by the cross-sectional area of the prism:

$$W = \frac{\sigma \cdot \varepsilon \cdot l}{\sigma_{f_c,\theta} \cdot \varepsilon_{f_c,\theta} \cdot l}.$$  \hspace{1cm} (2)$$

The calculation is done in the following sequence. From the family of curves in Figure 1 a curve with a certain temperature is selected and a diagram is constructed. For example, for temperature $\theta=20^\circ$C:

![Diagram](image)

**Figure 2.** Diagram “$\sigma_c$–$\varepsilon_c$” at the heating temperature of $20^\circ$C.

Using the formula (2) we get

$$\tilde{W} = \frac{\sigma \cdot \varepsilon \cdot l}{\sigma_{f_c,\theta} \cdot \varepsilon_{f_c,\theta} \cdot l} = \frac{\sigma \cdot \varepsilon}{0.0018}$$

and make a dependence table:

Using this table 1, we construct a graph $W=f(S)$ and determine its extreme $S=0.73$. We return to the diagram in Figure 2, where we find the values $\varepsilon_{cu,1,0} = 4.2 \ 0^\circ/00$. For $S=0.73$
Table 1. Dependence of the relative load potential on the relative stress

| S=σ/σ₀ | 0   | 0.2 | 0.4 | 0.6 | 1   | 0.8 | 0.7 | 0.6 |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|
| W      | 0.021111 | 0.095556 | 0.256667 | 1.595556 | 1.672222 | 1.666667 |
| S=σ/σ₀ | 0.165 | 0.069 | 0.044 | 0.029 |
| W      | 0.913 | 0.576533 | 0.488889 | 0.402778 |

Figure 3. Dependence of the relative load potential W on the relative stress S for the temperature θ=200°C.

Similarly, we determine the value of the parameters of the "stress-strain" diagram for concrete at other temperatures.

As it can be seen from Figure 3, the process of increasing the load potential after maximum force is slowed down for all specimens with different heating temperatures. The curve "W − P" or "W − σ" deviates from the vertical and at some value of the load (stress) the function has an extreme, after which there is a decrease in the load potential. The nature of the curve to the extreme point can be explained from the point of micro cracking or from the point of view of the theory of damage accumulation, and the process of reduction (release) of energy after the point of the function extreme is connected with the beginning and subsequent spreading of the macro cracks, since it is known that the energy of the body containing the crack is less than the energy of the body, which does not contain the cracks, and if the length of the crack increases, according to [9, 10], energy is released.

The values of the limit strains were determined on the diagrams "σ−ε" (Figure 1) by the stresses corresponding to the extreme of the load potential function [11] (Figure 2).

The determination of εₘₐₓ,θ on the basis of the energy approach allowed us to formulate the adjusted dependence of the limit strain on temperature, the dependence of the maximum deformation on the temperature, and the values of the parameters of the stress-strain diagram. According to these data, the stress-strain diagrams of concrete during compression and heating according to Eurocode EN 1992-1-2:2004 are calculated using the formulae of the first stage.

The class of heat-resistant concrete for the maximum acceptable temperature of application according to GOST 20910 shall be specified in the design in all cases.
For reinforced concrete structures made of heat-resistant concrete, operating under high temperature conditions, it is recommended to take a class of concrete with a compressive strength of not lower $f_{ck}=12.5$ MPa.

8. Conclusions
SNiP 2.03.04-84* standards were checked on according to the statutory order of the Ministry of Regional Development, Construction and Housing and Utilities Sector of Ukraine. These codes and regulations are applied to the design of concrete and reinforced concrete structures intended to operate under conditions of systematic exposure to elevated and high technological temperatures. It was proposed to develop a statutory instrument to replace SNiP 2.03.04-84* changing its status for the DBN one. The purpose of the project is to create a new national regulatory instrument, which is based on the modern achievements of

Table 2. Examples of application of heat-resistant concrete in structural elements of thermal units.

| Name of thermal unit       | Elements of heat-resistant concrete                                             | Temperature of working space of furnace, °C | Recommended concrete composition according to Table 5.1 [8] |
|----------------------------|--------------------------------------------------------------------------------|----------------------------------------------|----------------------------------------------------------|
| I. In ferrous metallurgy    |                                                                                  |                                              |                                                          |
| Blast furnace              | Furnace tuyers                                                                 | 1300                                         | 16, 19                                                   |
|                            | Mine, hearth bottom                                                            | 1200                                         | 11                                                       |
|                            | Gas outlets and an inclined gas pipeline                                       | 800                                          | 23, 24                                                   |
|                            | Dust collector                                                                 | 800                                          | 23, 24                                                   |
| Furnace for melting cast iron | Walls of fire bar and melting belt                                             | 1300                                         | 19                                                       |
| Blast furnace air heaters  | Walls (bottom part), bottom                                                    | 1200                                         | 11                                                       |
|                            | Bottom millstone                                                              | 800                                          | 23, 24                                                   |
| Sintering machines         | Bottom collector and gas outlets                                              | 800                                          | 23, 24                                                   |
|                            | Top collector                                                                  | 800                                          | 23, 24                                                   |
| Heating wells              | Stands of working cells, bottom plate, cover                                  | 1300                                         | 19, 21                                                   |
| Methodically heating furnaces | Insulation of gliding pipes and walls                                          | 1200                                         | 19                                                       |
| Pit furnace for slow cooling | Walls                                                                        | 800                                          | 23, 24                                                   |
| Coke-oven batteries        | Basements and base stones                                                      | 600                                          | 23, 24                                                   |
| II. In non-ferrous metallurgy |                                                                |                                              |                                                          |
| Graphite furnaces          | Walls                                                                         | 1200                                         | 11                                                       |
| Fluidized bed furnaces     | Vaults and grating                                                            | 1100                                         | 11, 15                                                   |
| Aluminium and magnesium electrolyser |                                                                | 1000                                         | 10, 11                                                   |
| Electrolysers of ultrapure aluminium |                                                                | 1000                                         | 10, 11                                                   |
| Ceramic, heating, firing furnaces | Walls, vaults and bottom plate                                               | 1200                                         | 11, 19                                                   |
| Dust cameras               | Walls and covering                                                            | 800                                          | 15                                                       |
III. In refining and petrochemical industry

| Tubular flameless combustion furnace of type B | Foundations, walls, vaults, bottom plate, pass walls | 800 | 10, 11 |
| Tubular flameless combustion furnace of type 3P | Walls, vaults, bottom plate | 850–1100 | 23–26, 33–37 |
| vertical torch furnaces of type HS (horizontal) | Walls of convection and radiation chambers, vaults, basement part | 900 | 23–26, 33–37 |
| Surface gas ducts of tubular furnaces | All elements | 600 | 22–32 |

IV. In building materials industry

| Tunnel kilns for firing ordinary clay bricks | The walls and vaults heating and cooling zones | 800 | 10-11 |
| | Walls and arches of the firing zone | 1100 | 19 |

V. In various industries

| Base stones and gas ducts for temperatures of 350°C | Walls, vaults | 350 | 2–4 |
| Base stones and gas ducts for temperatures of 800°C | The same | 800 | 6–9 |

Science, machinery and technology, advanced domestic and foreign experience of design and construction, and at the same time uses theoretical and experimental studies of the updated version of SNiP 2.03.04-84*.  

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