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The influence of pliability of supports on statistically undefined reinforced concrete elements at temperatures under -50°C

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Abstract. Performance of statistically undefined reinforced concrete constructions in harsh weather conditions is characterised by the presence of temperature forces. The strength of temperature forces is influenced by deformation and durability qualities of the concrete, crack formation and pliability of supports. Experiments were carried out in order to establish correlation between support pliability and temperature forces in bendable reinforced concrete elements in the conditions of limited mobility of supports. The result of the present research was experimental data on the changes of temperature forces depending on the horizontal pliability of swivel supports. Analytical dependency was suggested to calculate support pliability and change rigidity of reinforced concrete beams under the influence of load and low temperatures.

1. Introduction

Performance of statistically undefined reinforced concrete constructions in harsh weather conditions is characterised by the presence of temperature forces [1-4]. These forces, in contract to load pressure, can either increase or become zero. The increase of these forces is related to an increase of durability and deformation characteristics of the concrete in its frozen state, and the decrease is related to crack formation; deterioration of concrete structures as a result of cyclic freezing - melting; pliability of supports [5-8]. Current standards on reinforced concrete constructions are limited to recommendations to take into account changes in rigidity of constructions and temperature forces in their frozen state and in the cycle of freezing and de-freezing [9]. As a result, actual loads can lead to an increase of an acceptable level of stress in terms of crack endurance and durability.

The most frequent is the case when a bendable element is pinched or limited in its axial movements along the end face. In the former case when the end face is pinched, at low temperatures there is a bendable moment and the stretching force, and in the latter - only the stretching force. In experiments the simplest case was used - combining temperature and load pressure - a bendable element is limited at its end faces at the level of supporting parts in axial movements. The degree of horizontal pliability of supports, the level of transverse load pressure, number of freezing and de-freezing cycles were varied.

The aim of the research is to study the degree of influence of pliability of supports on temperature forces in bendable reinforced concrete elements in cases when support mobility is limited.

2. Materials and methods

Reinforced concrete beams of rectangular cross-section with dimensions of 10cm x 20cm and the length of 220cm have been used as experimental samples. The beams were reinforced by spacial bound frames. The structure of reinforced concrete beams is shown on figure 1.

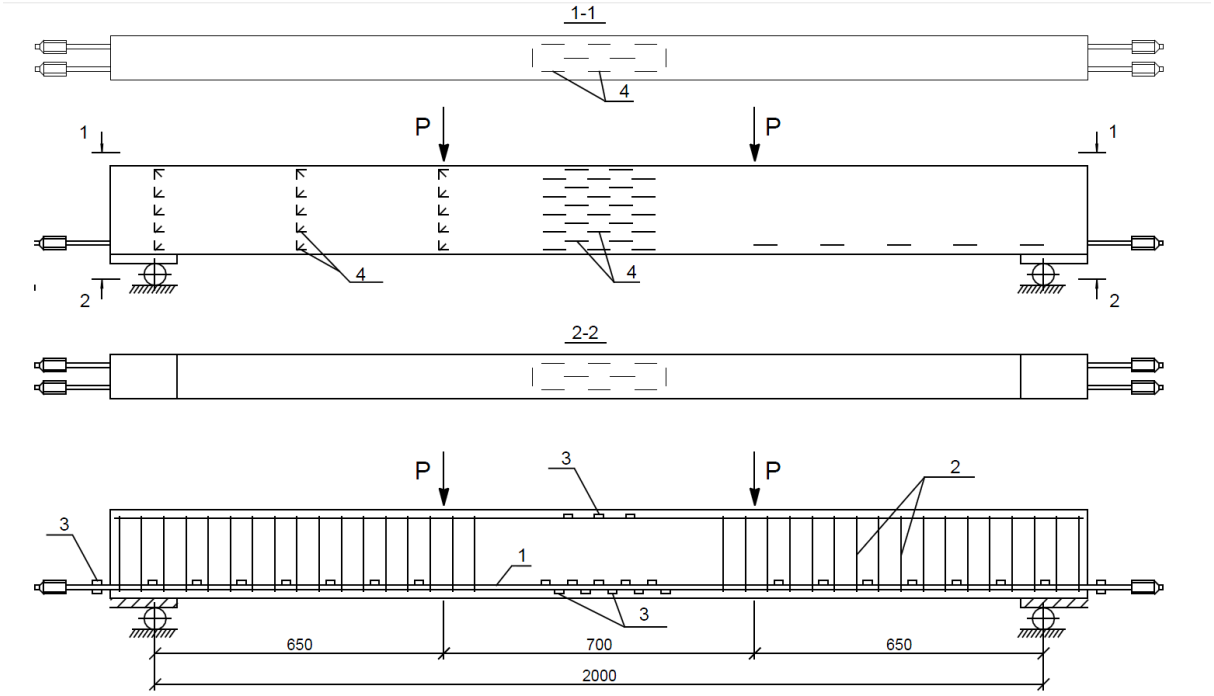

Figure 1. Structure of a beam and sensor location: 1 – working frame Ø 12mm; 2 – clamps Ø 12mm, 3 – sensors with a base of 20mm, sensors with a base of 50mm.

In the stretched zone the frame consisted of two rods with a diameter of 12mm from reinforced steel of class A400 (type 35 GS), and in the compressed zone for clamp fastening - two rods Ø 5 mm from cold-drawn rebar wire of class B500. Clamps were manufactured from rebar wire Ø 5 mm of class B500 and were located along the length of the beam with a 50mm step. In the clear bend zone clamps were not used. The rebar percentage was 1.29%.

The concrete's composition in terms of its weight is 1 : 1.2 : 2.2 with W/C=0.32. The super plastificator C-3 was injected into the concrete mix in the quantity of 0.7% and silicon organic liquid GKZh:-94 in the quantity of 0.15% of the whole mass of the cement. The expenditure of cement per 1m3 of the concrete mix was 500 kg. Frost-resistance of the concrete, determined according to the sped-up methodology [10], was F500. To prepare the concrete mix, granite crashed stone of 5-15mm fraction was used as well as river sand, portland-cement of brand 400.

Concreting of samples was carried out in a metallic demountable formwork. Compaction of the concrete mix was done on the vibration table. After three days of hardening, stripping was carried out. During the 28 days, samples were kept in damp sawdust, and then at temperatures +15±5 °C in the conditions of a production space with relative humidity of 60-65%.

To determine durability and deformation characteristics of concrete samples along with reinforced concrete elements, cubes of dimensions 10x10x10 and prisms with 10x10x40 cm were manufactured from the same concrete mix. Durability of concrete for the prism, its durability in terms of stretching and a module of elasticity were defined in accordance with requirements [11]. Samples - prisms with dimensions of 10x10x40 cm - were tested in a thermal room with corresponding negative temperatures.

Temperature deformations of the concrete were determined for concrete prisms (10x10x40 cm) according to the methodology outlined in [12-15]. Prior to testing, prisms went through water saturation under atmospheric pressure step by step for 7 days. Then the samples were enclosed in rubber cases in order to preserve humidity during the whole time of the experiment. Temperature in the prism's concrete was determined by the means of thermal pairs put inside. Measurements of load and temperature deformations were carried out by indicators of hourly type with division value of 0.001 mm and quartz extensions.

Beams with hinge-ductile supports were tested at the power point, the structure of which is presented on figure 3. The set up included a rough steel beam with massive end face stands, serving as support for the bendable element in order to limit its movement in axial direction. This was done by fixing rebar parts on end face stands by anchor screw-nuts. Pliability of supports was created by spring shims of specific rigidity.

Beam testing was carried out in a refrigerating chamber of the working volume of 12m3 and minimal negative temperature of -50°C. The set-up was fixed to the floor by anchor bolts.

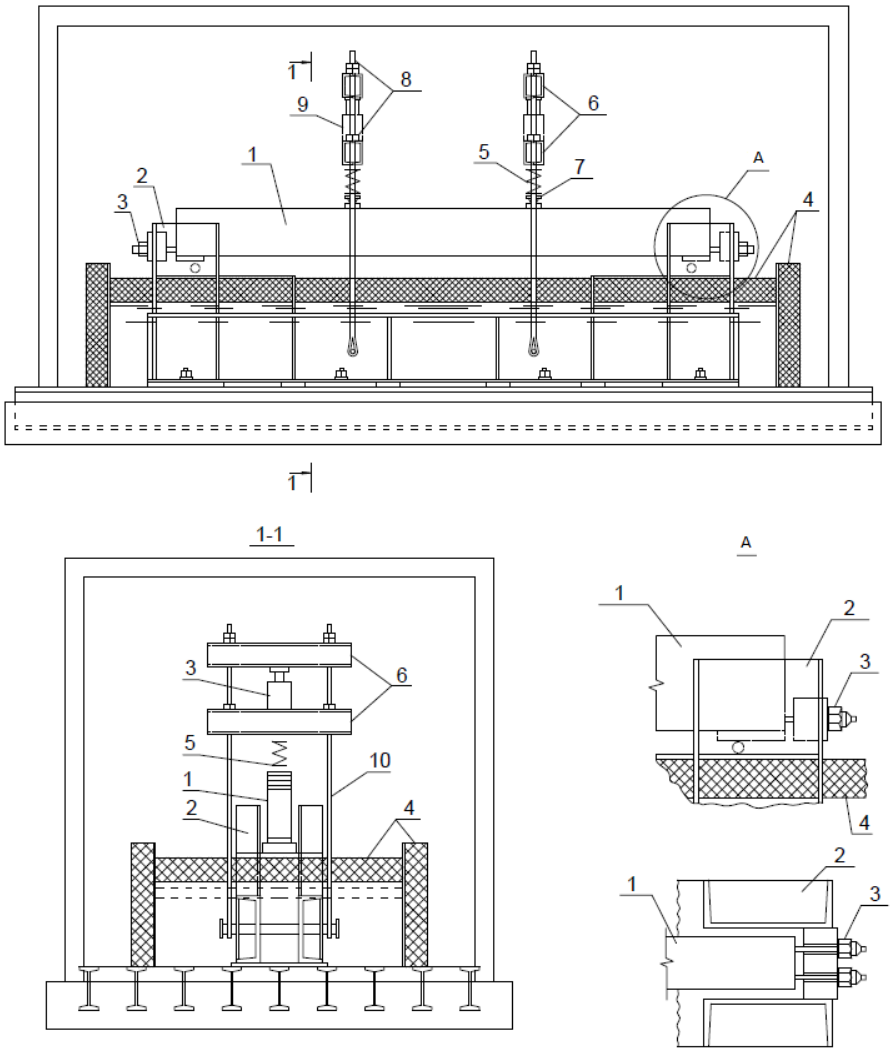

Figure 2. Structure of a power set-up to test beams:

1 - sample; 2 - metallic construction of a power stand; 3 - anchor screw-nuts on rebar parts; 4 - insulator; 5 - spring; 6 - traverses; 7 - bottom support; 8 - screw-nuts; 9 - hydraulic jack; 10 - hauls.

Beams were set up on two catenary supports and were loaded with two focused transverse forces until they reach the needed level by using hydraulic jacks, each 5 tf. Afterwards when springs were fixed by traverse and anchor screw-nuts, jacks were taken off. The beam then was held under pressure with a temperature of 15°C for one day. Then the sample was fixed at longitudinal offsets by anchor screw-nuts (knot I, figure 2) and was cooled to -50°C with 10°C steps. The beam was kept at each step of temperature decrease until the cross-section and the length were all the same temperature. After taking measurements from equipment installed on the beam, the next step of temperature lowering was carried out. After the temperature reached -50°C, the researched beam was warmed to +15°C. The age of samples by the time of testing was 180 days. Prior to testing beams were water-saturated for 7 days.

During the experiment the amount of traverse load (P/P_{ult}) and pliability of supports (Δ_{sup} / Δ_T) were varied.

During load and temperature pressure of beams the following things were measured: concrete and rebar deformation; movement of anchor screw-nuts and rebar extensions; temperature of concrete and rebar along beam cross-sections; opening width. The location of tools on the studied samples is presented on figure 3.

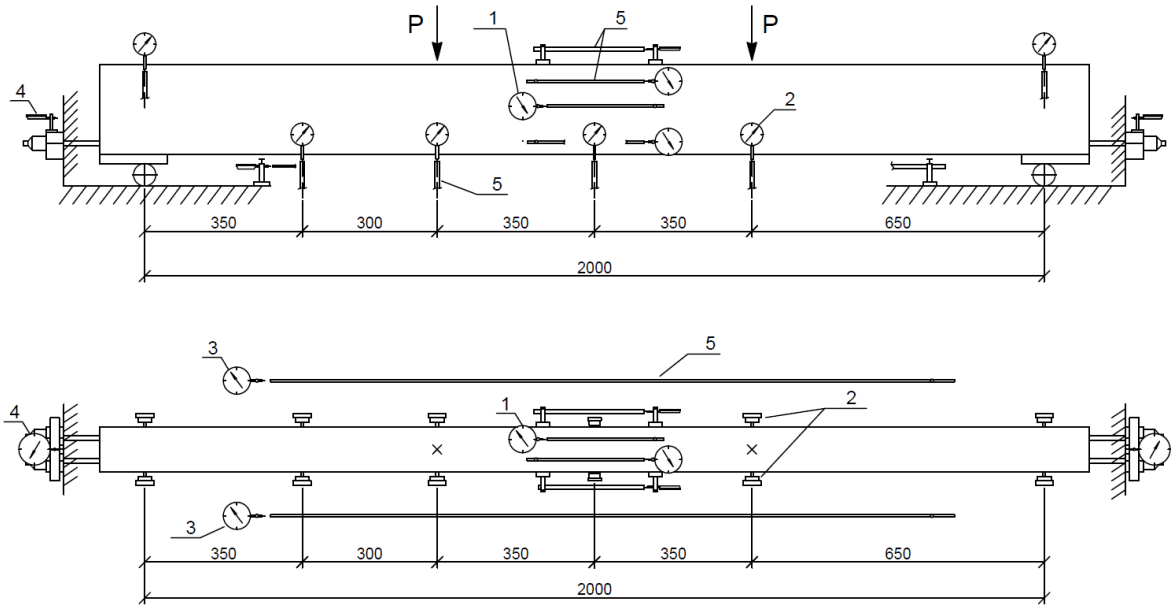

Figure 3. The location of tools on the sampled beam:

1 - indicator with a value division of 0.001mm in the zone of a clear bend; 2 - indicators (0.01mm) to determine sagging; 3 - indicators (0.001mm) on the load stand; 4 - indicators (0.001mm) to determine collapsing of anchor screw-nuts; 5 - quartz extensions.

3. Results

To calculate the temperature forces, stresses and strains in the statically indeterminate reinforced concrete structures, it is necessary to have data on the magnitude of the free thermal strains of the reinforcement and concrete. The values of these strains are characterized by the thermal strain coefficient (TSC).

Figure 4 shows changes in the free thermal strains of the concrete with the humidity W=5.0%, reinforcement (class A400) and reinforced concrete beams when the temperature is changed to -50°C.

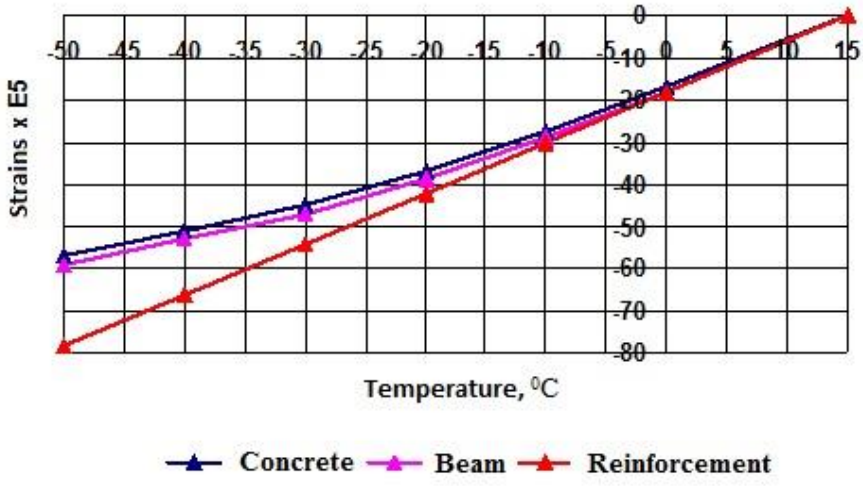

Figure 4. The thermal strains of the reinforced concrete beams, the concrete and reinforcement.

The graphs show when the temperature is lowered to -50 ° C, the thermal strains of the concrete change according to the non-linear law, i.e. the thermal strain coefficient (TSC) is not a constant value. At -50 ° C its value was $0.88 \cdot 10^{-5}$ 1 / ^{0}C. The reinforcement thermal strains of the unfixed reinforced concrete beam are less than the thermal strains of the reinforcement steel by 24%. At the same time, the value of the TSC of the steel remains constant and equal to $1.19 \cdot 10^{-5}$ 1/^{0}C throughout the temperature range. The reinforcement thermal strains in reinforced concrete beam structure are bigger than those of the reinforcement steel by 3.3%. This is due to the fact that the concrete has a smaller TSC than the reinforcement. As a result, the "preliminary reduction" effect of the beam by the reinforcement is created, and the additional reduction of the entire reinforced concrete sample is observed [16].

The deformation and strength characteristics of the concrete and reinforcement are presented in the table 1.

Table 1.

T^0C	Concrete					Reinforcement			
	W ,%	R_{bt} , MPa	$\frac{R_{bt}}{R_{bt,15}}$	$E_{bt} \cdot 10^{-3}$, MPa	$\frac{E_{bt}}{E_{bt,15}}$	R_s , MPa	$\frac{R_s}{R_{s,15}}$	$E_s \cdot 10^{-3}$, MPa	$\frac{E_s}{E_{s,15}}$
15	5.0	3.3	1.0	33.4	1.0	433	1.0	2.0	1.0
-50	5.0	5.5	1.67	38.4	1.15	465	1.07	2.08	1.04

The stretching strength of the concrete, its elasticity modules increase when the temperature decreases to -50 ^{0}C, respectively by 67% and 15%. In case of the decreasing temperature of the reinforced concrete elements these parameters change is taken into account with the help of the corresponding coefficients of the concrete working conditions [17-19]. The strength and elasticity modulus of reinforcement increase when the temperature decreases to -50 ^{0}C, respectively by 7% and

4%. These parameters change with the decreasing temperature is recommended to be taken into account in the accordance with the proposals [20].

$$R_{s,T} = R_s + 9.53 \cdot 10^{-3} \cdot (20 - T)^2 \quad (1)$$

$$E_{s,T} = E_s \cdot \left[1 + 9.3 \cdot 10^{-4} \cdot (20 - T)\right] \quad (2)$$

where:

- R_s, E_s - the strength and elasticity modulus of the reinforcement in the normal conditions,
- T - the negative temperature, ^{0}C.

In Figure 5 the temperature forces are presented, they appear in the statically indeterminate beam with the different initial transverse loading depending on the relative compliance of the supports (Δ_{sup}/Δ_T).

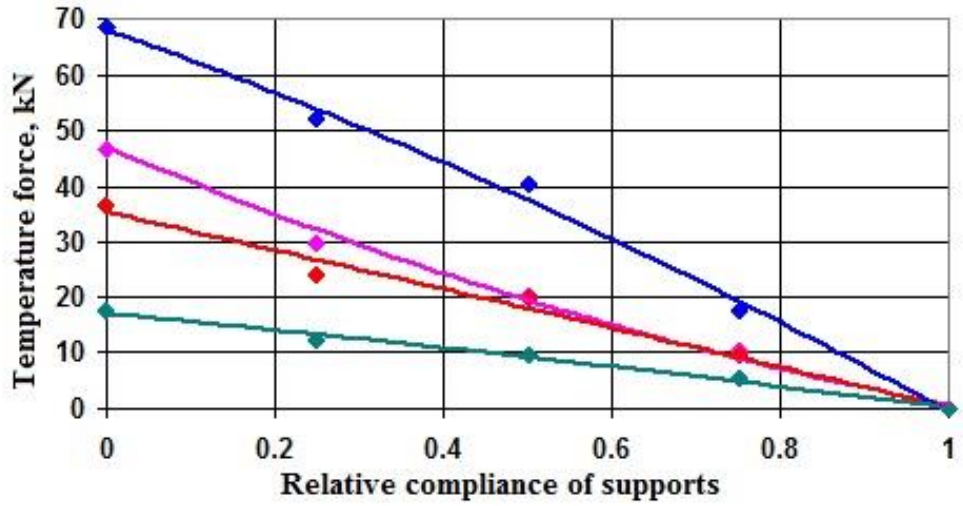

Figure 5. Temperature forces in the statically indeterminate beam:

the loading level 0; **the loading level 0.30;**
the loading level 0.45; **the loading level 0.65;**

In the compliance absence, the temperature tensile force decreases at the level of transverse loading P/P_{ult} = 0.3; 0.45; 0.65 respectively for 32%, 43%, 74% in the reinforced concrete beams. With the support compliance of 75%, the temperature force is reduced, on the average, by 74% for all the transverse loading levels.

To compare with the experimental data, the graphs of the change in the temperature beam tensile force obtained by calculation are presented in Figure 5. The calculation of the forces was based on the

equation solution of the temperature-force strain consistency of the beam and supports, through which the tensile force is transferred to the stand [21, 22]:

$$\Delta_T - \Delta_{\text{sup}} = \Delta_N \tag{3}$$

where:

- Δ_T - the temperature displacements of the free-lying beam at the level of the working reinforcement;
- Δ_{sup} - the displacements knots of the reinforcement inserts (the support compliance);
- Δ_N - the beam displacement created by the temperature force at the level of the work reinforcement.

From the equation (3) we obtain the expression to determine the temperature tensile force:

$$N_T = (\Delta_T - \Delta_{\text{sup}}) \Big/ \left(\frac{L \cdot e_0^2}{D} + \frac{L}{C} \right) \tag{4}$$

where:

- L - the beam length;
- e_0 - the eccentricity of the tensile temperature force according to the gravity center of the chosen section;
- D - the flexural beam rigidity in the zone of the pure bending;
- C - the axial beam rigidity in the zone of the pure bending.

The remaining notations are given in formula (3). The rigidity of the reinforced concrete beam was determined by the method described in [4, 22].

The calculation of the statically indeterminate reinforced concrete structures is carried out by the method of the successive approximations with the adoption of the real section rigidity. The rigidity is a variable that depends on the stress state of the structure. Thus, the rigidity of the reinforced concrete element and its temperature force are interdependent. The number of successive approximations can be reduced if the rigidity is initially set closer to the actual rigidity with the corresponding external load and temperature reaction. In this connection, the approximation of the obtained experimental data on the temperature reaction change was made depending on the transverse loading level and the support compliance. As a result, the following empirical dependence is obtained:

$$N_T = (1 - 1.13 \cdot P/P_{ult}) \cdot (1 - 0.978 \cdot \Delta_{\text{sup}} / \Delta_T) \cdot N_{T,0} \tag{5}$$

where:

- P/P_{ult} - the level of the transverse force loading;
- $\Delta_{\text{sup}}/\Delta_T$ - the relative support compliance;
- $N_{T,0}$ - the temperature force that occurs at the temperature of -50^{0}C in case of the non-shifting supports ($\Delta_{\text{sup}} = 0$).

4. Conclusion

The conducted researches showed that the thermal strains of the unfixed beam are by 26% less than the strains of reinforcement steel, i.e. it is necessary to take into account the forces arising due to the difference in the TSC of the concrete and reinforcement. The tensile strength of the water-saturated concrete at -50 °C increases by 67%, the elasticity modulus increases by 15%. The strength and elasticity modulus of the reinforcement, class A400, increase when the temperature decreases to -50 °C, respectively, by 7% and 4%.

In the support compliance absence, the temperature reactions are reduced by 74% in the statically indeterminate reinforced concrete beam with the increase in the transverse loading level to 0.65 of the ultimate load. The support shifting of 75% from the temperature displacements of the unfixed element leads to the decrease in the temperature forces, on the average, by 74% regardless of the level of the transverse loading.

Thus, the results of the conducted studies showed that the support compliance of the nodes of the statically indeterminate reinforced concrete structures leads to the significant decrease in the temperature reactions. The account of the support compliance and, correspondingly, the decrease in the temperature forces makes it possible to estimate the stress-strain state of the statically indeterminate structures more correctly.

The studies, the results of which are presented in this article, were carried out in case of the short-time transverse loading in the conditions of the single freezing to -50 °C. In the further studies, it is proposed to test statically indeterminate reinforced concrete beams in the conditions of the long transverse loading and cyclic freezing and thawing.

References

[1] Shapiro G I and Korovkin V S 2008 *Industrial and Civil Construction* On the issue of the stress-strain state of residential and public buildings under temperature effects **12** pp 5-7
[2] Kabantsev O V and Tamrazyan A G 2014 *Engineering and construction magazine* Accounting for changes in the design scheme in the analysis of the design work **5** pp 15-26
[3] Popov V M and Plyusnin M G 2014 *Bulletin of Civil Engineers* Estimation of load-bearing capacity of reinforced concrete structures in the natural conditions of cold climate **2** pp 42-47
[4] Istomin A D 2016 *Modern problems of calculation of reinforced concrete structures, buildings and structures for emergency impacts. Collection of reports of the International Scientific Conf. dedicated to the 85th anniversary of the Department of Reinforced Concrete and Stone Structures and the 100th Anniversary of the Birth of N N Popova* Efforts in statically indeterminate reinforced concrete elements during their operation in the negative temperature range pp 140-146
[5] Almazov V O and Istomin A D 1989 *Offshore oil and gas production facilities* Thermal forces in reinforced concrete structures of marine hydraulic structures pp 104-110
[6] Tamrazyan A G 2014 *Industrial and civil construction* Concrete and reinforced concrete: problems and prospects **8** pp 30-33
[7] Klamer E L, Hordijk D A and Kleinman C S 2006 *3rd International Conf. on FRP Composites in Civil Engineering* Debonding of CFRP laminates externally bonded to concrete specimens at low and high temperatures (Miami, Florida, USA)
[8] Almazov V O and Istomin A D 1986 *Influences of external factors on hydraulic structures* Influence of the water saturation method on the temperature deformation of concrete during freezing pp 162-169
[9] SP 63.13330.2012. 2012 *FAU FTSS* Concrete and reinforced concrete structures. Basic provisions p 165
[10] GOST 10060-2012 2014 *Standardinform* Concretes. Methods for determining frost resistance (Moscow) p 20

[11] GOST 10080-2012 2013 *Standardinform* Concretes. Methods for determining the strength of control samples (Moscow) p 36
[12] Moskvin V M, Kapkin M M, Savitsky A N and Yarmakovskiy V N 1973 *Stroyizdat* Concrete for construction in harsh climatic conditions p 172
[13] Durcheva V N and Mayorova M A 2002 *Hydraulic engineering* Tensometric measurements of free deformations of concrete dams **11** pp 6-9
[14] Koval S B and Molodtsov M V 2012 *Herald of SUSU-2012* Temperature deformation of concrete **38** pp 23-25
[15] Istomin A D and Kudryavtsev A V 2016 *Industrial and civil construction* The work of statically indeterminate ferro-concrete elements in conditions of negative temperatures **7** pp 51-55
[16] Pinus B I, Pinus Zh N and Khomyakova I V 2015 *Bulletin of the Irkutsk State Technical University* Changes in the structural properties of concrete during cooling and freezing **2 (97)** pp 111-116
[17] Milovanov A F and Samoylenko V N 1980 *Concrete and reinforced concrete* Accounting for the effects of low temperatures in the calculation of structures **3** pp 25-26
[18] SP 52.105.2009 2012 *FITC FIC Construction* Reinforced concrete structures in cold climate and on permafrost soils. Concrete structures for cold climate and permafrost soil (Moscow) p 35
[19] Meshkov V Z 1975 *Thesis of Cand. tech. sciences* Features of the operation of core hot-rolled reinforcement in reinforced concrete structures at low temperatures p 229
[20] Rzhanitsyn A R 1982 *Higher School* Structural mechanics p 400
[21] Istomin A D and Istomin A S 205 *Scientific Review* Temperature forces in a statically indeterminate reinforced concrete beam when it is frozen to -50°C **24** pp 88-91