Influence of Freeze-Thaw Temperature on Load-Bearing Capacity of Steel-Concrete Beams Carrying Transverse Loads

Yuriy Famulyak ¹, Andriy Hrytsevych¹, Justyna Sobczak-Piastka²

¹ Lviv National Agrarian University, Faculty of Civil Engineering and Architecture, 80381, V. Velykoho Str., Dublyany, Zhovkva district, Lviv region, Ukraine
² UTP University of Science and Technology in Bydgoszcz, Faculty of Civil and Environmental Engineering and Architecture, Al. Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland

justynas@utp.edu.pl

Abstract. The use of steel-concrete structures in which, external or extra-strong non-stressed sheet reinforcement are widely used in the stretched (sometimes in the compressed zone) in industrial construction as well as in the process of bridges and tunnels construction. Such structures are continuously thermal loaded during operation. Existing calculation methods of steel-concrete structures do not allow accurate estimation of the influence of freeze-thaw temperatures because there are contradictions considering this problem. The method of frost resistance calculating in Ukraine researches concrete cubes but it does not take into account the existence of reinforcement in the construction, its quantity and placement in the cross-section. This problem became even more relevant under conditions of Ukraine transition to the European design standards. According to the demand of the Eurocode the number of cross reinforcement in the back-up area is increased in comparison with national design standards. Single-span steel-concrete beams were manufactured and examined in order to determine the influence of freeze-thaw temperature on the constructions. Flat deformed reinforcement was adopted for the perception of tensile forces. To determine the strength characteristics of concrete, cubes and prisms were additionally made from the same concrete as the beams. To determine the freezing point of the beam and measure its internal temperature, 10 thermocouples were introduced into the beam's body. On the basis of the adopted research method a graph of the freezing rate of the experimental beams and the destructive influence of freeze-thaw temperature on the load-bearing capacity of the steel-concrete beams were obtained.

1. Introduction

The use of steel-concrete structures in which external or extra-strong non-stressed sheet reinforcement are widely used in the stretched (sometimes in the compressed zone) in industrial construction as well as in the process of bridges and tunnels construction. Such structures are continuously thermal loaded during operation. Existing calculation methods of steel-concrete structures do not allow accurate estimation of the influence of freeze-thaw temperatures because there are contradictions considering this problem. The method of frost resistance calculating in Ukraine researches concrete cubes but it does not take into account the existence of reinforcement in the construction, its quantity and placement in the cross-section. This problem became even more relevant under conditions of Ukraine transition to the
European design standards. According to the demand of the Eurocode the number of cross reinforcement in the back-up area is increased in comparison with national design standards.

The well-known methods (algorithms) of calculation of reinforcement constructions under conditions of freezing temperatures are provided in different resources. The steel-concrete constructions are distinguished by the lack of the protective concrete layer of working reinforcement as it is made in the shape of steel strip or sheet and it is placed on the most tensile face of cross section of the construction. Thus, the known methods of calculation are not available for steel-concrete constructions because these methods do not fully describe the work and behavior of such structures. The given statement is also true for cyclic action of freezing and freeze-saw temperatures [1-5].

The temperature difference in steel-concrete span structures is mainly of due to the fact that the temperature of steel part of the construction with high thermal conductivity responds more significantly to the daily (seasonal) fluctuations of air temperature than the reinforced part of the construction with low thermal conductivity. In addition, thin elements of steel constructions (sheet reinforcement) during a short sunlight are warming much faster than concrete ones. Such difference leads to the formation of microcracks (cracks caused by temperature loads) in the grafting zone of metal with concrete.

Significant reduction of plastic properties of steel is observed under conditions of cooling below -10 °C, and steel becomes fragile at a temperature below -45 °C [6-7] (figure 1).

Negatively freezing temperatures also affect the concrete. It can be concluded that low temperatures reduce the carrying capacity of steel-concrete structures by 15 ÷ 20%, but this percentage may differ under conditions of the cyclic freeze-saw temperature changes.

![Figure 1. Graphs of temperature changes by months for 2013-2017 according to the data of weather station (WMO ID 33393) "Airport" Lviv](image)

2. Results and discussions

To determine the negative influence of freeze-saw temperature on load-bearing capacity of steel-concrete structures the authors have tested steel-concrete beams, concrete cubes and prisms. Tested samples of the steel-concrete beams with external strip reinforcement were made at the plant Open Joint Stock Company ‘House building plant’ №2 in the village of Murovane, Pustomyty district, Lviv region. The design of tested samples is shown in figure 2. Beams research was conducted under three different conditions:

1. Beams loading under ordinary natural conditions of work \( T = 20^\circ \pm 25^\circ \text{C} \);
2. Beams loading after a certain number of freezing cycles \( T = -30 \pm 4^\circ \text{C} \) and thawing cycles \( T = +18 \pm 4^\circ \text{C} \) but not later than 5 days after thawing;
3. Beams testing after 20 cycles of immersion in a 5% salt solution (NaCl) for the freezing time of the beam (24 h) and drying at +18 ±4 °C for a thawing time of 12 h.

To determine the rate of the beam freezing and its internal temperature 10 thermocouples were introduced into the beam's body (figure 3). On the basis of the adopted research method a graph of the
rate of the experimental beams freezing and the destructive influence of freeze-thaw temperature on the load-bearing capacity of the steel-concrete beams were obtained. Graph of beam freezing was constructed according to the results of the observation (figure 4).

![Figure 2. Construction and reinforcement of tested steel-concrete beams of B1 type (concrete C12/15), B2 type (concrete C20/25), B3 type (concrete C30/35)](image)

Freezer Vestfrost VT 407 with tested samples in it

The layout of thermocouples for the temperature determining in the beam body

Devices for temperature measurement in the beam body

![Figure 3. The temperature measurement in the beam body](image)

![Figure 4. Rate of beam freezing according to thermocouple impressions](image)
According to the indicators of thermocouples it was found that the complete freezing of the beam to -20 °C occurred in 24 hours under the chamber temperature $T = -30 \pm 4^\circ C$ and the temperature fields of beams freezing were constructed (figure 5).

![Temperature change in beam section during freezing](image)

**Figure 5.** Temperature change in beam section during freezing
Experimental studies using microscopy showed that some microcracks occur in concrete before it was loaded and after the cycles of freezing-thawing depending on the concrete type and the number of cycles (figure 6). The microcracks are divided into two types. The first type is characterized as the microcracks at the interface of metal to concrete joint. They were called microcracks of the bond zone. The second type is characterized as the microcracks directly in the cement-sand stone.

That is, we consider the presence of microcracks in concrete (reinforced concrete) before static loading.

Figure 6. Temperature-corrosion cracks due to the effect of the freeze-saw temperature in the tested beams of the B1 series (concrete C12/15): a) a crack fragment in the upper part of the beam after 30 cycles; b) crack producing corrosion in the zone of metal sheet to concrete joint after 20 cycles; c) after 10 cycles; d) after 20 cycles; e) the beam face corrosion after 30 cycles;

During experimental studies the beams were designed and designed with a condition of destruction in a zone of pure bending. According to this scheme the beams $a$ and $d$ were destroyed despite they were not thermal loaded (figure 7). All other beams affected by thermal loading were destroyed in the area of transverse forces due to a sloping crack (figure 7).

On the basis of experimental researches generalization of the bearing capacity of steel beams was made and the influence of freeze-thaw temperature on the work of such structures was determined. As it can be seen from the graph (figure 8, 9, 10) the bearing capacity of C12/15 concrete type decreased by 43.54%, the cube from the same class of concrete - by 17.89%. The bearing capacity of the concrete from the class C20/25 decreased by 22.21%, the bearing capacity of the cube from the same concrete decreased by 9.7% The bearing capacity of the beam of C30/35 concrete type decreased by 12.57% and the bearing capacity of the cube, decreased by 6.83%.
Figure 7. Beams view of B1 type after testing: a) have not been subjected to temperature influences; b) 10 cycles of freezing-thawing; c) 20 cycles of freezing-thawing; d) 30 cycles of freezing-thawing; e) were placed in 5% salt solution for freezing period of 20 cycles

Figure 8. Graphs of the dependence of the loss of steel-concrete beams bearing capacity. Steel-concrete beams made of C12/15 concrete type: a) design values of beam carrying capacity; b) have not been subjected to temperature influences; c) were placed in 5% salt solution for freezing period of 20 cycles d) 10 cycles of freezing-thawing; e) 20 cycles of freezing-thawing; f) 30 cycles of freezing-thawing
Figure 9. Graphs of the dependence of the loss of steel-concrete beams bearing capacity. Steel-concrete beams made of C20/25 concrete type: a) design values of beam carrying capacity; b) have not been subjected to temperature influences; c) were placed in 5% salt solution for freezing period of 20 cycles d) 10 cycles of freezing-thawing; e) 20 cycles of freezing-thawing; f) 30 cycles of freezing-thawing

Figure 10. Graphs of the dependence of the loss of steel-concrete beams bearing capacity. Steel-concrete beams made of C30/35 concrete type: a) design values of beam carrying capacity; b) have not been subjected to temperature influences; c) were placed in 5% salt solution for freezing period of 20 cycles d) 10 cycles of freezing-thawing; e) 20 cycles of freezing-thawing; f) 30 cycles of freezing-thawing
3. Conclusions

Making conclusions we may define the following:

a. Experimental researches allowed obtaining of the qualitative scheme of freezing temperature areas of the cross section of steel-concrete beams.

b. During the freezing process metal elements of the cross-section (longitudinal and transverse reinforcement) act as a kind of “concentrators” of temperature changes that affect the uneven freezing of the cross-section.

c. During the freezing-thawing process there are the microcracks at the interface of metal to concrete joint and directly in the sand-cement stone and even before the static loading of the structure. Their quantity and number depend on the concrete type as well as on the number of thermal cycles and reinforcement.

d. Freezing-thawing processes of steel-concrete beams change the nature of their destruction regardless of the concrete type.

e. According to the results of experimental studies it is inappropriate to use low-type concrete in steel-concrete structures which are cyclically affected by freeze-saw temperatures.

References

[1] F. Klymenko, “Steel-concrete structures with external strip reinforcement”, Kyiv: Budivelnyk, p. 88, 1984.

[2] M. Ben-Amoz, “Continuum model of heat conduction in laminated composites”, Int. J. Eng. Sci., Vol. 9, N 11. pp. 1075–1085, 1971.

[3] T. Bobalo, “Comparison of the results of experimental research of reinforced concrete beams with the results of calculation according to the existing national norms”, Architecture and farm building: Bulletin of National Agrarian University, Lviv, №13, pp. 34-43, 2012.

[4] F. E. Klimenko, V. K. Barabasch, „Festigkeit und Verformbarkeit und ökonomische - Möglichkeiten vorgespannter Stahlbetonbalken mit auBerer Rippenstahlblech - bewehrung”, Wissenschaftliche Zeitschrift der Hochschule fur Architektur und Bauwesen Weimar, № 4/5, pp. 364 – 368, 1977.

[5] P. Klimenko, „Untersuchungen an vorgespannten stalblechbewehrten Stahlbetonbalken”, Bauplanung – Bautechnik, №4, pp. 179-182, 1975.

[6] H. L. Malhotra, “The Effect of Temperature on the Compressive Strength of Concrete”, Magazine of Concrete Research-Wexham Springs: Cement and Concrete Association, V.8, №23, pp. 85-94, 1956.

[7] J. A. Purkiss, I. W. Dougill, „Apparatus for compression tests on concrete at high, temperatures”, Magazine of Concrete Research, № 3, 1973.