

Fire resistance of lightweight steel-concrete slab panels under high-temperature exposure

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Abstract. Lightweight steel concrete structures (LSCS) - an innovative energy-efficient building structure type that can be used both as load-bearing and as enclosing one. They consist of profiled steel - usually galvanized and cold-bent - filled with a monolithic foam concrete with a 400kg/m³ density and with fiber cement sheets sheathing. These structures can be used in industrial and civil buildings as internal and external bearing and enclosing wall structures and as slabs, energy-efficient roof covering. According to the LSCS production method, prefabricated panels (walls and slabs) and building site performed constructions are distinguished. The paper presents the testing results with the aim to determine the fire resistance limit of a slab panel fragment by bearing capacity (R), loss of integrity (E), loss of heat insulating capability (I) and fire hazard class. Two samples of a slab panel fragment were selected for the fire resistance high-temperature tests. The actual fire resistance limit of samples of the slab panel fragment is at least REI 60 with a uniformly distributed load 4 kN/m².

1 Introduction

Lightweight steel-concrete slab panels are the type of lightweight steel concrete structures (LSCS, [1-2]). They are well-known as energy-efficient composite steel and concrete structures in which as filling concrete monolithic (pouring) foam concrete of the D400...D1000 grade acts; as a rule, LGSS (light gauge steel structures, [3],[4] and etc.) act as profile steel, and permanent formwork functions performing fiber cement panels. The design forces from all loadings are also perceived by foam concrete and profile steel. Similar structures with rolled sections can also be classified as LSCS.

Foam concrete is produced both in a factory and on a construction site, usually has a density of 400...600 kg/m³ for slabs and is used in the innovative building structures type - lightweight steel concrete structures (LSCS). Diatomite, microsilica, granite, perlite and vermiculite are used in foam concrete production [5].

In scientific articles [6-9] and etc, other additives are known that are used in lightweight concrete and affect their performance.

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The effect of temperature loss in the enclosing structures linear elements is presented in the article [10].

In [11-13], the behaviour of the reinforced concrete slab during fire exposure was considered, and fire resistance calculations were described.

It is known and proved that prefabricated and monolithic lightweight concretes are usually fire-resistant materials that can withstand increased temperature effects [14-16].

For example, in [17] experimental study of the post-fire mechanical performance of six simply-supported composite slabs after exposure to hydrocarbon fire heating with a maximum temperature of 700°C and duration time of 90 min was conducted. The results show that the overall collapse of the composite slabs will not take place even when there is serious torsion of thin-walled steel beam and more than one serious crack in the concrete, and the maximum deflection of the slabs is less than $L/400$ for bearing the uniform load of 2 kN/m²; The ultimate load of the composite slab specimens after fire for which the commonly used nails are set is 14.2% greater than that with the shear keys made with thin-walled steel plate.

In [18] a new composite panel system based on external insulation has been developed for light gauge steel framing floors to provide a higher fire resistance rating under fire conditions. This article presents the details of an experimental investigation of light gauge steel framing floors made of both the conventional (with and without cavity insulation) and the new composite panel systems under standard fires. Analysis of the fire test results showed that the thermal and structural performance of externally insulated light gauge steel framing floor system was superior to conventional light gauge steel framing floors with or without cavity insulation.

Many other scientific articles [19-24] are devoted to the work of floors at elevated temperatures

In one of our previous works [1] we investigated the load-bearing capacity of an LSCS-slab panel under the action of a static load at normal operating ambient temperatures, where the value of 10.71...17.53 kN/m² was experimentally revealed, a similar task under the condition of fire impact was not solved.

Therefore, the purpose of this work is to determine the fire resistance limit of the slab panels made of LSCS under fire action.

Research objectives:

- 1) Determination of the actual limit of the effective fire resistance of the slab for a standard load of 4 kN/m².
- 2) Determination of the temperature gradient along with the thickness of the slab (temperature on the unheated surface)
- 3) Determination of the deformability of the slab under fire action.

2 Materials and Methods

The experimental setup is shown in figure 2. The panel based on LSCS (figure 1) with dimensions 4000x800x216 (mm) has special hinge supports with the rigid plate to avoid local pushing of the panel.



Fig. 1. Appearance of the sample before testing (in vertical position)



Fig. 2. Type of experimental setup as: (a) front view Description I; (b) side view.

Loading is being applied with four concrete blocks connected in the uniform system maintaining equality of efforts in each of them. To correspond to the load in the experimental installation to uniformly distributed under each block, distribution elements are installed so that each lack transmits two strip (perpendicular to the span) loads to the panel, which together corresponds to a conventional beam with 4 concentrated loads located at an equal distance from each other.

Measurement of displacements is made using deflection indicators T1, T2 and T3, located in the middle of the span of the slab – on both sides and in the middle between them.

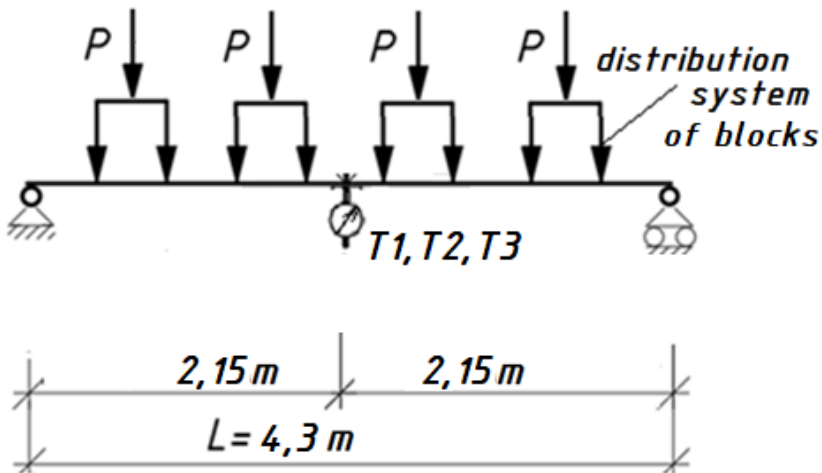


Fig. 3. Test scheme

Thus, the load generated by the equipment is close to uniformly distributed from the point of view of structural mechanics (Figure 3).

Testing was carried out to determine the fire resistance limit of a slab panel fragment by bearing capacity (R), loss of integrity (E), loss of heat insulating capability (I) and fire hazard class.

Two samples of a slab panel fragment were produced for the fire resistance tests.

The appearance of one of the sample before testing is shown in the figure 1. Panel fragment drawing is presented in figure 4. Technical document for panels: STO 06041112-2018. «Panels made of steel-concrete structures based on heat-insulating non-autoclaved monolithic foam concrete, profile steel with fiber-cement sheets covering» (Russian Standard)

GPN is the channel thin-walled profile with the height of the web equal to 204mm. GPS is the C-shaped thin-walled profile with flanges with the height of the edge equal to 200mm.

The test method was applied according to GOST 30247.1-94 «Elements of building constructions. Fire-resistance test methods. Loadbearing and separating constructions» (Russian Standard).

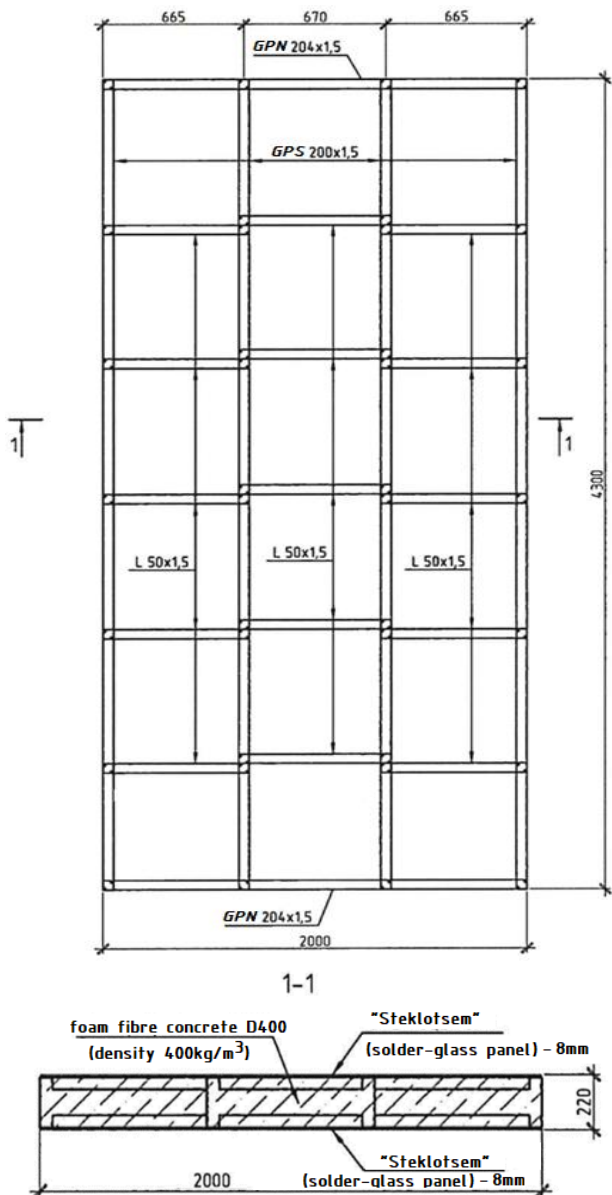


Fig. 4. Panel fragment drawing

In summary, the test method aims to determine time from the beginning of thermal action on the structure until one or several limit states on fire resistance occur subsequently, taking into account the functional purpose of the structure.

3 Results and Discussion

The following specimen installations were used for the test.

A sample of a fragment of the slab panel was installed unbraced horizontally on the opening of the fire oven. The sample scrubbing was performed on two sides. The evenly distributed load during testing was 4 kN/m^2 .

During the tests, the temperature in the furnace fire chamber was kept constant following the requirements of GOST 30247.0-94. Excessive pressure in the fire chamber of the furnace 5 minutes after the test start at a level of $\frac{3}{4}$ of the sample height was maintained within $(10 \pm 2) \text{ Pa}$. The fire action on the samples is from below.

The test duration is 60 minutes.

During the tests, the following test results and Observations were obtained.

Specimen 1.

0÷60 min – changes in appearance, integrity, and heat-insulating ability of the sample were not registered; maximum deflection to the heated side was 88.4 mm. The experiment was terminated after the declared fire resistance limit was reached.

Specimen 2.

0÷60 min – changes in appearance, integrity, and heat-insulating ability of the sample were not registered; maximum deflection to the heated side was 91.2 mm. The experiment was terminated after the declared fire resistance limit was reached.

Change of average temperature measured in the fire chamber of the furnace is shown in Figures 5, 6; change of average temperature measured on the unheated surfaces of the samples during testing are presented in tables 1, 2

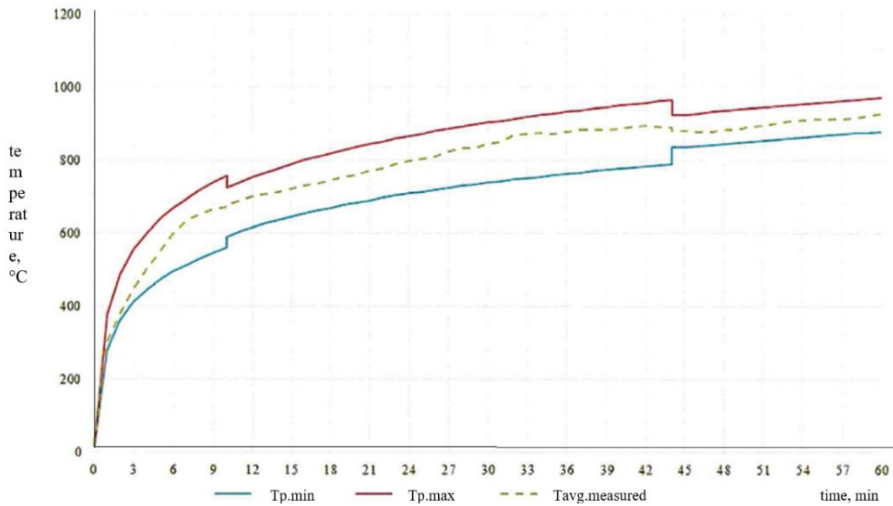


Fig. 5. Temperature change in the fire chamber of the furnace during testing of sample №1: $T_{p.min}$ – minimum permissible furnace temperature; $T_{p.max}$ – maximum permissible furnace temperature; $T_{avg.measured}$ – average measured temperature in the fire chamber of the furnace when testing the sample.

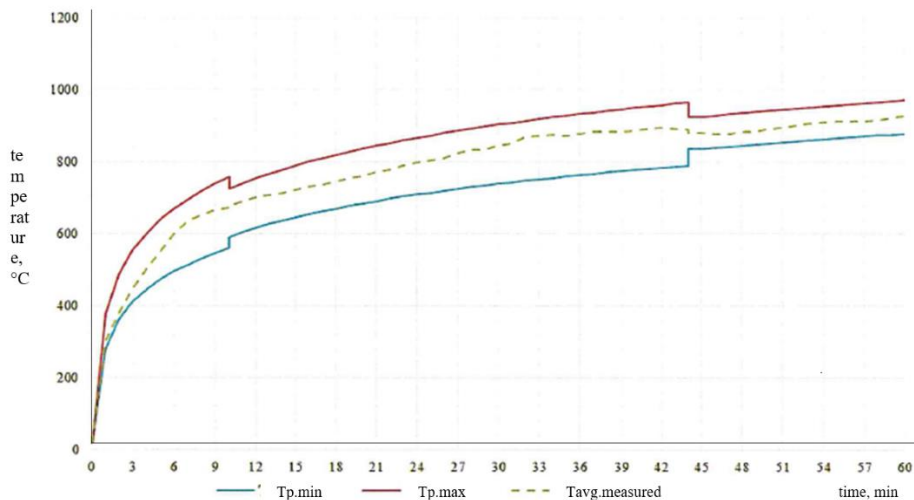


Fig. 6. Temperature change in the fire chamber of the furnace during testing of sample №2: $T_{p.min}$ – minimum permissible furnace temperature; $T_{p.max}$ – maximum permissible furnace temperature; $T_{avg.measured}$ – average measured temperature in the fire chamber of the furnace when testing the sample.

Table 1. Temperature on the non-exposed side of the sample № 1

Time, min	Temperature according to thermoelectric converters on the non-exposed side of the sample №1, °C					
	TP №1	TP №2	TP №3	TP №4	TP №5	T avg.
0	20	21	21	21	22	21
5	20	21	21	21	23	21
10	20	21	21	22	23	21
15	21	22	22	23	24	22
20	22	22	22	24	24	23
25	22	23	23	25	25	24
30	23	24	23	26	25	24
35	23	26	24	28	25	25
40	25	30	25	30	26	27
45	50	32	35	37	27	36
50	79	39	54	66	27	53
55	87	46	71	84	27	63
60	88	59	87	92	28	71

Table 2. Temperature on the non-exposed side of the sample №2

Time, min	Temperature according to thermoelectric converters on the non-exposed side of the sample №2, °C					
	TP №1	TP №2	TP №3	TP №4	TP №5	T avg.
0	20	21	21	21	22	21
5	20	21	21	21	23	21
10	20	21	22	22	23	22
15	21	22	22	23	24	22
20	22	22	23	24	24	23
25	22	24	23	27	25	24
30	23	26	23	26	25	25
35	23	26	24	30	25	26
40	28	30	29	30	26	29
45	59	32	39	37	37	41
50	85	39	54	66	42	57
55	96	46	71	84	53	70
60	108	69	87	92	68	85

The authors summary test results are presented in Table 3.

The test duration was 60 minutes.

Table 3. Summary test results

№ pos	Name of regulatory document	Name of observed parameter	Parameter value		
			by the regulatory document	Actual	
				Specimen №1	Specimen №2
1	par. 8.1.2 GOST 30247.1- 94	Loss of bearing capacity (R):	- due to a collapse of the structure;	have not been detected	
			- occurrence of critical deflections:		
			- if a deflection has reached L/20 i.e. 20 cm	have not been reached	
			- if a deform rate has reached $L^2/(9000h)$, i.e. 0,8 cm/min	have not been reached	
2	par. 8.1.2 GOST 30247.1- 94	Loss of heat insulating ability (I) due to temperature increase on the unheated surface of the structure:	- an average of more than 140 °C compared with the surface temperature of the structure before testing;	have not been detected	
			- more than 180 °C at any point on the surface of a structure in comparison to the temperature of the surface of the structure before testing or more than 220 °C, regardless of the temperature of the structure before testing	have not been detected	
3	par. 8.1.3 GOST 30247.1- 94	Loss of integrity (E) as a result of trough cracks or holes formation which let combustion products or flames trough:	- ignition of a cotton swab for 10 s after presenting to the sample	have not been detected	

4 Conclusion

1. It is shown that monolithic foam concrete filling has a positive effect on the fire resistance of LSCS slab panels and, as a result, on the fire protection of LSGS slab panels when exposed to elevated temperatures. Foam concrete is proposed to be used not only as energy-efficient heat-insulating material but also as a means of increasing the fire resistance of load-bearing structures
2. The actual fire resistance limit of samples of the slab panel fragment is at least RE 60 with a uniformly distributed load 4 kN/m^2 . During the experiment on the unheated floor surface, the maximum temperature set was $108 \text{ }^\circ\text{C}$ after 60 minutes of temperature exposure. At the same time, the temperature on the heated surface had values of about $1000 \text{ }^\circ\text{C}$. This circumstance confirms the high fire resistance in terms of thermal insulation capacity (I60)
3. The maximum deflection of the samples was 91.2 mm , which does not meet the requirements of rigidity under normal power loads, but meets the requirements of permissible movements under high-temperature exposure (fire tests)

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