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Lightweight steel concrete structures technology with foam fiber-cement sheets

Технология легких сталебетонных конструкций из пенобетона и фиброцементных листов

V.A. Rybakov*,
K.G. Kozinetc,
N.I. Vatin,
V.Z. Velichkin,
V.I. Korsun,
Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

Канд. техн. наук, доцент В.А. Рыбаков*,
д-р техн. наук, профессор Г.Л. Козинец,
д-р техн. наук, профессор Н.И. Ватин,
д-р техн. наук, профессор В.З. Величкин,
д-р техн. наук, профессор В.И. Корсун,
Санкт-Петербургский политехнический университет Петра Великого,
г. Санкт-Петербург, Россия

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Abstract. Lightweight steel concrete structures (LSCS) constitute an innovative building structure type that can be used both for load-bearing and enclosing purposes. They consist of steel profile – usually galvanized and cold-bent – filled with a monolithic foam concrete with 200 kg/m^3 and more density value, and with fiber cement panel sheathing. These structures can be used in industrial and civil buildings as internal and external bearing and enclosing wall structures, and as slabs. According to the LSCS production method, prefabricated panels (walls and slabs) and building site performed constructions are distinguished. The article presents the experimental studies on bearing capacity of LSCS subspecies i.e. representing slab panels made of galvanized steel profile, medium grade density monolithic foam concrete D400, and sheathing boards “Steklotsem”. The paper confirms that such panels can be used in civil buildings and withstand the appropriate load, regulated by the current codes and rules. Moreover, it has been experimentally proved that the foam concrete, despite its own extremely low strength class, actually includes in the operation, preventing such effects as stability local loss, destruction and profile steel elements warping and increases the slabs overall load capacity by 20–25 %.

Аннотация. Легкие сталебетонные конструкции (ЛСБК) – инновационный тип конструкции, которые могут быть как несущим, так и ограждающими. Они состоят из профилированной стали – обычно оцинкованной и холодногнутой – заполненной монолитным пенобетоном с плотностью 200 кг/м^3 и более и обшивкой из фиброцементных панелей. По способу производства ЛСБК различают сборные панели (стены и плиты) и монолитные. Представлены экспериментальные исследования несущей способности подвидов ЛСБК: панелей из оцинкованного стального профиля, монолитного пенобетона средней плотности D400 и обшивочных панелей «Стеклоцем». Подтверждается, что такие панели могут использоваться в гражданских зданиях и выдерживать соответствующую нагрузку, регулируемую действующими строительными нормами. Кроме того, экспериментально доказано, что пенобетон, несмотря на свой низкий класс прочности, фактически помогает предотвращать потери местной устойчивости, разрушение и деформацию профилей стальных элементов в поперечном сечении и увеличивает общую несущую способность плит на 20–25%.

1. Introduction

In the 21st century, much attention is paid to the construction industry development, including building materials and structures.

One of these areas are metal constructions. With the innovative technologies advent and the metallurgy development, they are becoming increasingly popular in the construction process.

The use of lightweight steel thin-walled structures is becoming increasingly popular due to a number of advantages of this structure, namely low metal consumption, availability of manufacturing and

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transportation, high manufacturability, speed of construction, and consequently, lower costs for the facility construction.

LSTS is widely used abroad, and now they are on the Russian market [1].

Nowadays, much attention is paid to the energy efficiency issue, as well as to ensuring the fire resistance and fire preservation of structures.

The article [2] shows that the most efficient, from the point of view of energy saving, are buildings built via LSTS frame technology. In [3–5], the behavior of the reinforced concrete slab during fire exposure was considered, and fire resistance calculations were described.

What are the classic structures can be replaced by steel and steel-concrete? The roof system montage via LSTS is an alternative variant of wooden truss structures [6]. In low-story and modular construction may be applied walls made of steel, sheathed with drywall [7].

But the combination of LSTS with foam concrete is the most popular [8], which may be applied both as enclosing walls [9] and as a floor construction [10]. The work of this technology, the physic-mechanical characteristics, and the behavior of steel elements are described more detailed in [11–14].

The articles [15–19] describe the experience of using foam concrete in the floors and walls construction, and indicate possible methods for strengthening the structure to achieve sufficient strength.

In order for the building structure to be durable, it is necessary to comply with the temperature and moisture conditions [20–22], especially as concerns cellular concrete, which is foam concrete. In the articles [23–24], the consequences of the violation of the specified regime are described on the example of another cellular concrete - aerated concrete.

The effect of temperature loss in the enclosing structures linear elements is presented in article [25]. In [26], the joint work of LSTS and polystyrene concrete as a heater is considered; it is shown that this materials combination is able to minimize heat loss of the building envelope.

The lightweight steel thin-walled structures (LSTS) use in Russia is hampered by the absence of an appropriate regulatory framework. The existing regulatory documents cannot be applied, because they do not take into account the local stability in the early stages of loading loss possibility factor of LSTS [27].

As in any building materials and structures, for example, in concrete with synthetic fiber reinforcement [28], when designing buildings and structures using light steel gauge structures, it is quite important to not forget about its strength characteristics.

In [29], a scheme of tests for “pure” bending, created by applying two concentrated forces equidistant from the supports, was used. This scheme is convenient from the point of view of the stress-strain state; however, it does not reflect the operation of the structures under the actual application of loads on the floor. Numerical studies of the stress-strain state beam structures with external sheet reinforcement are presented in [30].

The steel pipes filled with concrete local stability analysis, as one of the reinforced concrete structures types, is considered in article [31]. For the steel thin-walled structures calculation, the CFSteel program, which operates both in Russian and European standards, can be applied [32].

The opportunities of cold-bent notched c-shaped profile members’ application are considered in [33].

The work's aim is to identify the nature of the work and insulating non-autoclaved monolithic foam fiber concrete with a 400 kg/m^3 bulk density, profile steel with fibrous cement cladding, slabs structures samples bearing capacity assessment.

Tasks of the research:

1) The research of slab three identical samples to the bearing capacity loss.
2) One of the samples, when bringing it to complete destruction, work nature research.

2. Test methods

During the research, 5 series of 4 foam concrete cubes samples with various additives were considered.

The identical samples’ amount is 3 pcs.

The samples' geometrical dimensions are presented in Appendix 1 and correspond to Figure 1. Overall dimensions are 800 x 4000 (mm).

The support and the loading are shown in Figure 2.

Figure 1. The samples' general view

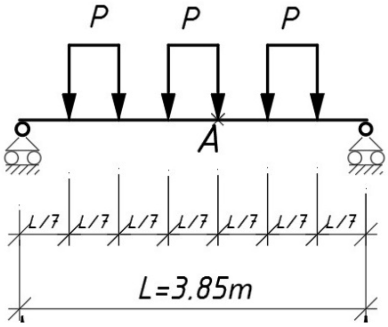


Figure 2. The samples' support and load

The support is free, on special hinge supports, as a result of which the tested panels' free span turned out to be L = 3.85 m

Loading – via 3 jacks, each of which is attached from above to a rigid metal own transverse traverse fixed to the force floor via two racks. From below, jacks rest against an additional metal element or directly into the steel conditionally non-deformable channel shape longitudinal traverse. The longitudinal traverse transmits forces through distribution metal elements to concrete prisms with a section of 150 x 150 mm and a length of 800 mm, which coincides with the panel's width. These concrete prisms (6 pieces) imitate a concentrated load on the test panel. Between the panel and the concrete prisms, wooden gaskets are laid over the entire contact surface of the prisms and the panel.

Every jack is connected to the same source, in which the external load is specified and its constant value is maintained in all three jacks.

Thus, the accepted loading scheme 6 with concentrated forces can, as is known from the structural mechanics laws, be considered conditionally loaded with a uniformly distributed load, the constancy of which does not depend on the tested samples deformed axis.

To determine the each sample individual points' deflection two deflectometers were installed.

Three samples were investigated.

3. *Results and Discussion*

Sample 1. The test results are presented in Table 1 and Figures 3–4.

Table 1. Slab panel's test results (sample 1)

Load, kgf	Deflectometers testimony, mm*10^{-2}		Deflections, mm		**Slab deflection, mm**
	1	2	1	2	
0	7254	10393	0	0	**0**
100	7388	10507	1.34	1.14	**1.24**
200	7504	10620	2.5	2.27	**2.385**
300	7677	10755	4.23	3.62	**3.925**
400	7855	10931	6.01	5.38	**5.695**
500	8049	11111	7.95	7.18	**7.565**
600	8220	11302	9.66	9.09	**9.375**
700	8445	11500	11.91	11.07	**11.49**
800	8670	11768	14.16	13.75	**13.955**
900	8972	12053	17.18	16.6	**16.89**
1000	9220	12340	19.66	19.47	**19.565**
1100	9597	12670	23.43	22.77	**23.1**
1200	10020	13070	27.66	26.77	**27.215**
1300	10500	13700	32.46	33.07	**32.765**

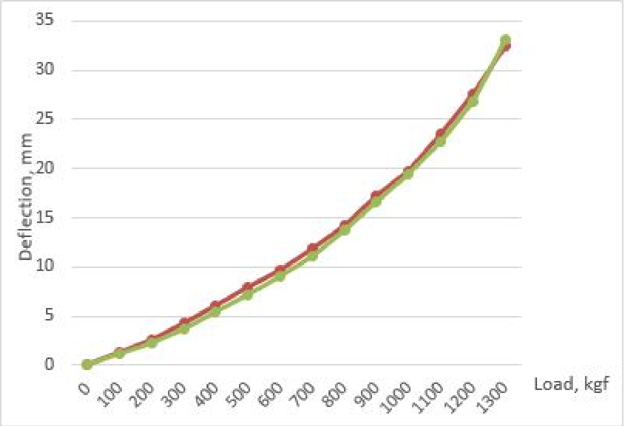


Figure 3. Samples 1 loading diagram (sensor 1 and sensor 2)

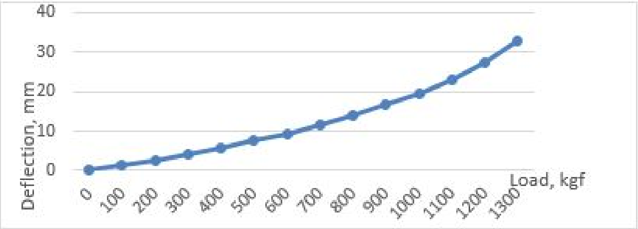


Figure 4. The deflections curve in the panel's middle (sample 1)

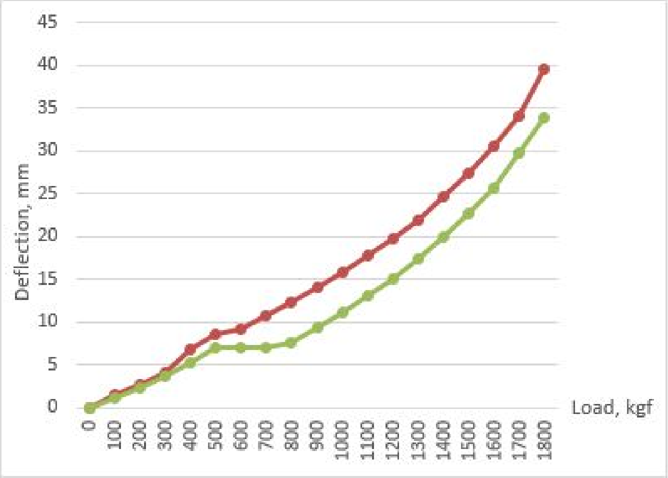
The maximum load was 1.3 tf per 1 jack with a 33 mm deflection, which corresponds to 1,266 kgf/m^2. The weight of the transfer equipment and the initial deflection of the panel's own weight were not taken into account.

Further loading was not made, since when trying to maintain a constant effort in the jacks, an increase in displacements occurred, which indicated the exhaustion of the bearing capacity.

Sample 2. The test results are presented in Table 2 and Figures 5–6:

Table 2. Slab panel's test results (sample 2)

Load, kgf	Deflectometers testimony, mm*10^{-2}		Deflections, mm		**Slab deflection, mm**
	1	2	1	2	
0	9218	12422	0	0	**0**
100	9366	12303	1.48	1.19	**1.335**
200	9482	12194	2.64	2.28	**2.46**
300	9635	12051	4.17	3.71	**3.94**
400	9899	11886	6.81	5.36	**6.085**
500	10075	11722	8.57	7	**7.785**
600	10139	11715	9.21	7.07	**8.14**
700	10295	11715	10.77	7.07	**8.92**
800	10454	11666	12.36	7.56	**9.96**
900	10625	11480	14.07	9.42	**11.745**
1000	10800	11300	15.82	11.22	**13.52**
1100	11005	11110	17.87	13.12	**15.495**
1200	11200	10910	19.82	15.12	**17.47**
1300	11415	10680	21.97	17.42	**19.695**
1400	11680	10430	24.62	19.92	**22.27**
1500	11969	10145	27.51	22.77	**25.14**
1600	12278	9848	30.6	25.74	**28.17**
1700	12633	9442	34.15	29.8	**31.975**
1800	13183	9030	39.65	33.92	**36.785**



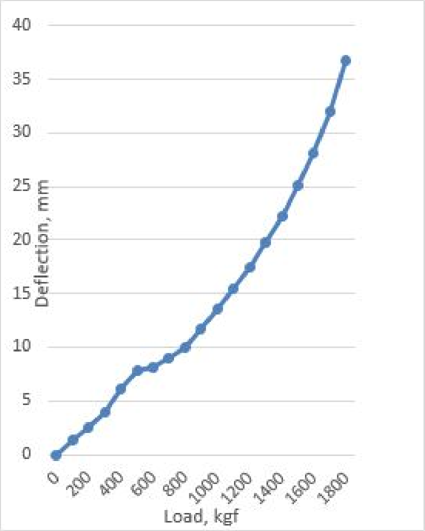


Figure 5. Sample 2 loading diagram (sensor 1 and sensor 2)

Figure 6. The deflections curve in the panel's middle (sample 2)

The maximum load was 1.8 tf per 1 jack with a 37 mm deflection, which corresponds to 1,753 kgf/m^2. The weight of the transfer equipment and the initial deflection of the panel's own weight were not taken into account.

Further loading was not made, since try to maintain a constant effort in the jacks, an increase in displacements occurred, which indicated the exhaustion of the bearing capacity.

Sample 3. The test results are presented in Table 3 and Figure 7–8:

Table 3. Slab panel's test results (sample 3)

Load, kgf	Deflectometers testimony, mm*10^{-2}		Deflections, mm		**Slab deflection, mm**
	1	2	1	2	
0	1706	11065	0	0	**0**
100	1862	10906	1.56	1.59	**1.575**
200	2054	10721	3.48	3.44	**3.46**
300	2251	10517	5.45	5.48	**5.465**
400	2448	10320	7.42	7.45	**7.435**
500	2684	10094	9.78	9.71	**9.745**
600	2918	9854	12.12	12.11	**12.115**
700	3161	9632	14.55	14.33	**14.44**
800	3410	9330	17.04	17.35	**17.195**
900	3742	9042	20.36	20.23	**20.295**
1000	4065	8687	23.59	23.78	**23.685**
1100	4581	8240	28.75	28.25	28.5
1200	5369	7424	36.63	36.41	36.52
1300	5733	7063	40.27	40.02	40.145

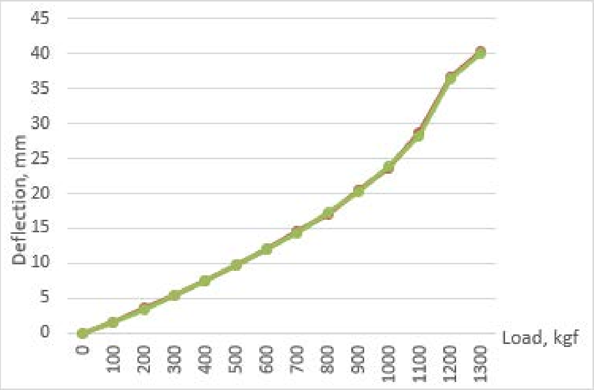


Figure 7. Sample 3 loading diagram (sensor 1 and sensor 2)

The maximum load was 1.1 tf per 1 jack with a 28 mm deflection, which corresponds to 1,071 kgf/m^2. The weight of the transfer equipment and the initial deflection of the panel's own weight were not taken into account.

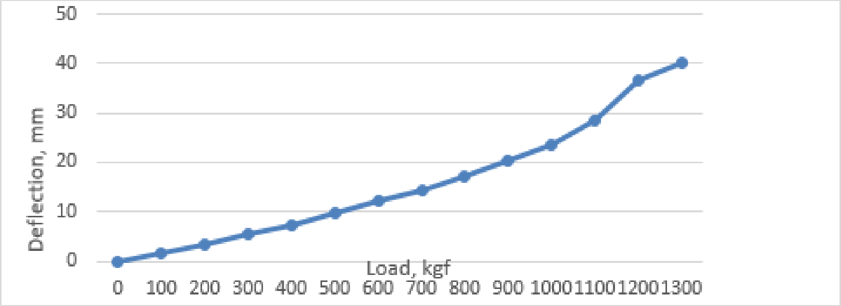


Figure 8. The deflections curve in the panel's middle (sample 3)

Sample 3 was subjected to a complete destruction by efforts maintaining in the jacks, accompanied by an increase in displacements and, at the same time, a decrease in the magnitude of the efforts in the jacks. In the destruction course, the various sizes cracks presence in foam concrete, facing panels "Steklotsem" local cracking is noted. The final loss of bearing capacity is caused by the profile steel destruction (Figure 9) – the achievement of the tensile strength in the stretched fibers and the local loss of stability in the upper edges of the compressed zone.

Figure 9. The destruction in the "dangerous" section

Figure 10. The destruction's general view

The dangerous section location is the left bar under the central jack (the third (out of five) in a row from left to right "concentrated" force – point A) – Figure 2,10.

This circumstance is due to the fact that the maximum bending moment ("pure" bending) occurs within the space between the bars of the central jack with a transverse force equal to zero. In addition, the two most "dangerous" sections are the sections under the central jack bars, in which a transverse force already occurs, equal to a half the force in the jack. In one of these sections the destruction appeared.

4. Conclusion

1. The research has shown that the maximum load on the slab varies from 1.1 tf to 1.8 tf per jack, which corresponds to the slabs' bearing capacity 1,071….1,753 kgf/m^2

2. The ultimate load value corresponds to a certain range of deflection values – 28 ... 37 mm, which indicates a possible difference in the stiffness samples' values (most likely due to different characteristics of foam concrete – humidity, density, etc.), which indirectly indicates the capture of foam concrete on the part of the stress.

3. It was shown that the panels' final destruction occurs on the profile steel and foam concrete increases the slabs overall load capacity by 20–25 %.

4. It was shown that the filling of the construction of monolithic foam concrete, incl. due to the high degree of adhesion, prevents the loss of stability of the profile steel elements

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Vladimir Rybakov,*
+7(964)331-29-15; fishermanoff@mail.ru

Galina Kozinetc,
+7(964)387-05-00; galina4410@yandex.ru

Nikolai Vatin,
+7(921)964-37-62; vatin@mail.ru

Viktor Velichkin,
+7(921)654-54-68; V.Velichkin2011@yandex.ru

Volodymyr Korsun,
+7(921)757-82-60; korsun_vi@mail.ru

Владимир Александрович Рыбаков,*
+7(964)331-29-15;
эл. почта: fishermanoff@mail.ru

Галина Леонидовна Козинец,
+7(964)387-05-00;
эл. почта: galina4410@yandex.ru

Николай Иванович Ватин,
+7(921)964-37-62; эл. почта: vatin@mail.ru

Виктор Захарович Величкин,
+7(921)654-54-68;
эл. почта: V.Velichkin2011@yandex.ru

Владимир Иванович Корсун,
+7(921)757-82-60; эл. почта: korsun_vi@mail.ru