ISSN 2304-6295

Condition Load Effect Factor of Profile Steel in Lightweight Steel Concrete Structures

Rybakov, V.A[1*]

[1] Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia
* fishermanoff@mail.ru

Key words:
Lightweight steel concrete structures (LSCS); Slab panels; Load-bearing capacity; Profile steel condition load effect factor

Abstract:
Lightweight steel concrete structures (LSCS) - an innovative 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 400…1200 kg/m^3 density, and with fiber cement sheets sheathing. In view of the current Standarts, codes and scientific literature there is no methodology for foam filling when calculating the strength of such structures, the goal is to determine the condition load effect factor of profile steel in LSCS. In this paper, based on experimental data, a comparison of two types of floor slabs is considered: LSCS fabricated of foam concrete with a density of 400 kg/m^3 and similar slabs made of profile steel elements, fiber-cement sheets without filling with monolithic foam concrete. Three samples of panels of each type were loaded with uniformly distributed load, which gradually increased from zero to failure values using three jacks, each of which transmitted the load to the slab at two points. 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, crushing and profile steel elements cross-section warping and increases the slabs overall load capacity by 20-25%., which corresponds to a condition load effect factor of at least 1.2…1.25.

1 Introduction

Lightweight steel concrete structures (LSCS) are a type of composite steel and concrete structures in which as filling concrete monolithic (pouring) foam concrete of the D100...D1000 grade acts; as a rule, LGSS 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.

LGSS 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 LGSS frame technology. In [3], [4], [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 LGSS 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 LGSS with foam concrete is the most popular [8], which may be applied both as enclosing walls and as a floor construction [9]. The work of this technology, the physic-mechanical characteristics, and the behavior of steel elements are described more detailed in [10], [11], [12].

The articles [13], [14], [15], [16], [17] 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 [18],[19] .

In order for the building structure to be durable, it is necessary to comply with the temperature and moisture conditions [20], especially as concerns cellular concrete, which is foam concrete. In the articles [21], [22] 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 [23]. In [24], the joint work of LGSS 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 (LGSS) 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 LGSS [25].

As in any building materials and structures, for example, in concrete with synthetic fiber reinforcement [26], when designing buildings and structures using light steel gauge structures, it is quite important to not forget about its strength characteristics.

In [27], 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 [28].

The steel pipes filled with concrete local stability analysis, as one of the reinforced concrete structures types, is considered in article [29]. For the steel thin-walled structures calculation, the CFSteel program, which operates both in Russian and European standards, can be applied [30].

The opportunities of cold-bent notched c-shaped profile members application are considered in [31]. Initial in-plane rotational stiffness of welded RHS T-joints with axial force in main member are presented in [32].

In the actual codes regulating the calculation methods of steel structures, such as:

- EN 1993-1-5 (2006): Eurocode 3: Design of steel structures - Part 1-5: General rules - Plated structural elements
- EN 1993-1-1 (2005): Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
- EN 1993-1-3 (2006): Eurocode 3: Design of steel structures - Part 1-1: General rules – Supplementary rules for cold-formed members and sheeting
- SP 16.13330.2017 "Steel structures", SP 260.1325800.2016 "Thin-walled steel Structures of cold-rolled galvanized profiles and corrugated sheets and SP 294.1325800.2017" steel Structures. Design rules» (all of them are Russian codes),

there is no information about the real values of condition load effect factor of profile steel elements filled with any material, including monolithic foam concrete

EN 1994-1-1:2004 Eurocode 4: «Design of composite steel and concrete structures — Part 1-1: General rules and rules for buildings» intended for the design of steel-reinforced concrete structures using concrete strength classes not lower than C20/25 and LC20/22.

The requirements of the SP 266.1325800.2016 «Steel-reinforced concrete. Design rules» (Russian codes), also do not apply to the design and calculation of structures containing light concrete density less than 500kg /m^3.

Thus, the only way to calculate LSCS is to consider them as steel structures (or light steel gage structures – LGSS) – depending on the profile steel type, which is part of the LSCS) with the adoption of the condition load effect factor value γ_c , equal to 1.0 – i.e, assuming non-participation in the work of light concrete filling at all.

On the other hand, in accordance with paragraph 9.2. GOST 27751-2014 (Russian codes), the condition load effect factor of materials, structures and foundation is allowed to be established on the basis of experimental data.

The research goal of the paper is to determine the condition load effect factor of LSCS on the example of slab panels of steel concrete structures based on heat-insulating non-autoclaved monolithic foam concrete, profile steel with fiber-cement sheets.

Research objectives:

1. Determination of the bearing capacity of three panels based on LSCS under the action of uniformly distributed load
2. Determination of bearing capacity of three similar panels, but without foam concrete filling-on the basis of light steel gage structures (LGSS)
3. Analysis of the results and identification of the actual coefficient of working conditions of light steel concrete floors

2 Methods

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

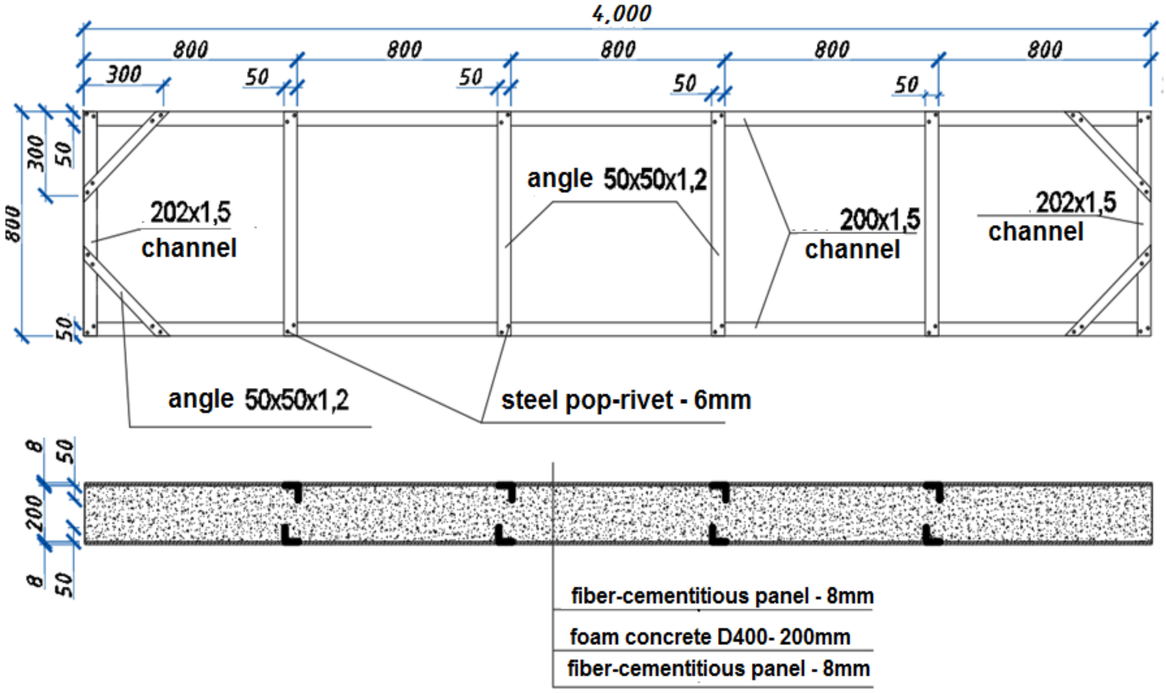
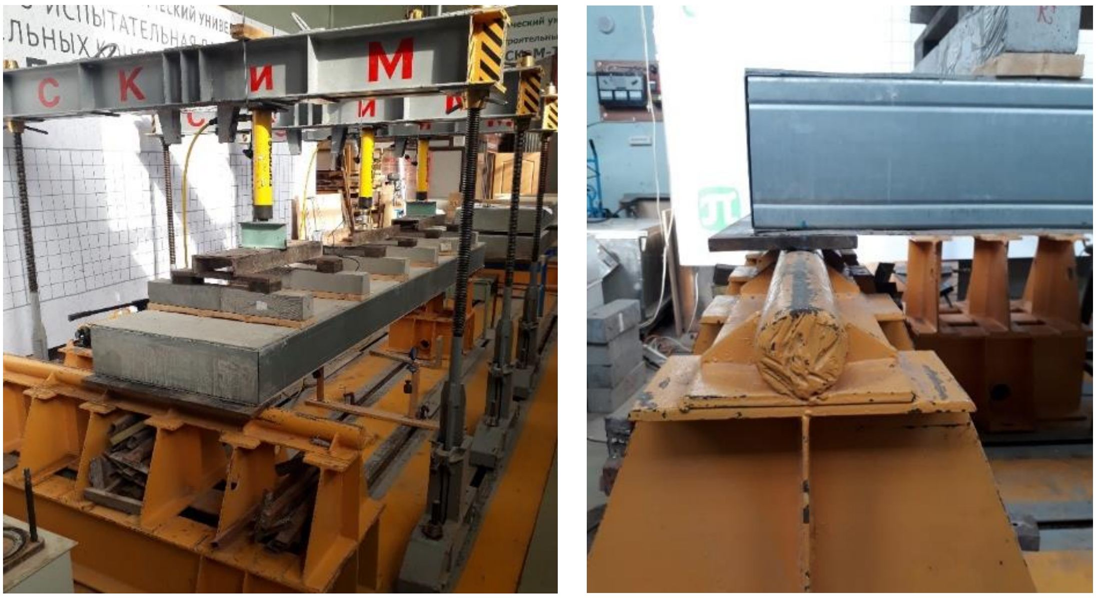


Figure 1 – Scheme of samples to be tested

Loading is being applied with three hydraulic lacks connected in the uniform system maintaining equality of efforts in each of them.



(a) (b)

Figure 2 – Type of experimental setup

To correspond to the load in the experimental installation (figure 2(a)) uniformly distributed under each lack, 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 six concentrated loads located at an equal distance from each other (figure 3).

Measurement of displacements is made by means of deflection indicators T1 and T2, located in the middle of the span of the slab – on both sides.

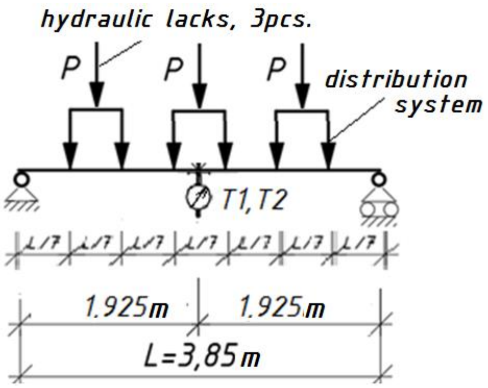


Figure 3 – Test scheme

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

The total weight of the distribution elements is 260 daN.

3 The Results

Tables 1-2 show the values of displacements at the points calculated on the basis of the deflection indicators readings T1 and T2.

Table 1 – The results of the test of the ceiling panel of LGSS

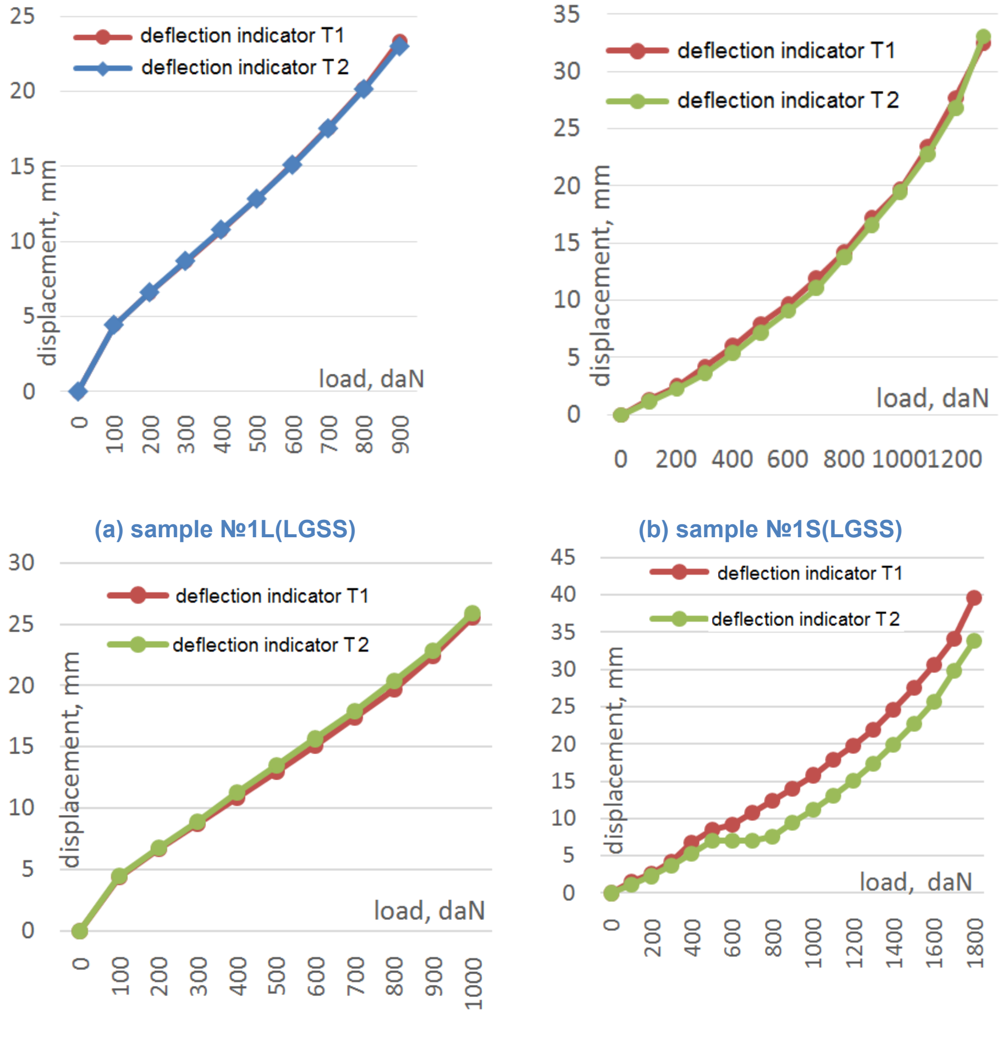
sample №1L		sample №2 L		sample №3 L	
Load, kgs	Slab deflection, mm	Load, kgs	Slab deflection, mm	Load, kgs	Slab deflection, mm
0	0	0	0	0	0
100	4.435	100	4.425	100	4.815
200	6.59	200	6.725	200	7.02
300	8.675	300	8.82	300	9.26
400	10.75	400	11.075	400	11.355
500	12.825	500	13.21	500	13.57
600	15.125	600	15.385	600	15.85
700	17.535	700	17.625	700	18.235
800	20.17	800	20.025	800	20.975
900	23.16	900	22.65	900	24.385
-	-	1,000	25.72	1,000	29.54

Table 2 – The results of the test of the ceiling panel of LSCS

sample №1C		sample №2C		sample №3C	
Load, kgs	Slab deflection, mm	Load, kgs	Slab deflection, mm	Load, kgs	Slab deflection, mm
0	0	0	0	0	0
100	1.24	100	1.335	100	1.575
200	2.385	200	2.46	200	3.46
300	3.925	300	3.94	300	5.465

400	5.695	400	6.085	400	7.435
500	7.565	500	7.785	500	9.745
600	9.375	600	8.14	600	12.115
700	11.49	700	8.92	700	14.44
800	13.955	800	9.96	800	17.195
900	16.89	900	11.745	900	20.295
1,000	19.565	1,000	13.52	1,000	23.685
1,100	23.1	1,100	15.495	1,100	28.5
1,200	27.215	1,200	17.47	1,200	36.52
1,300	32.765	1,300	19.695	1,300	40.145
-	-	1,400	22.27	-	-
-	-	1,500	25.14	-	-
-	-	1,600	28.17	-	-
-	-	1,700	31.975	-	-
-	-	1,800	36.785	-	-

The average deflections of the plates and deformation diagrams are represented on the figure 4.

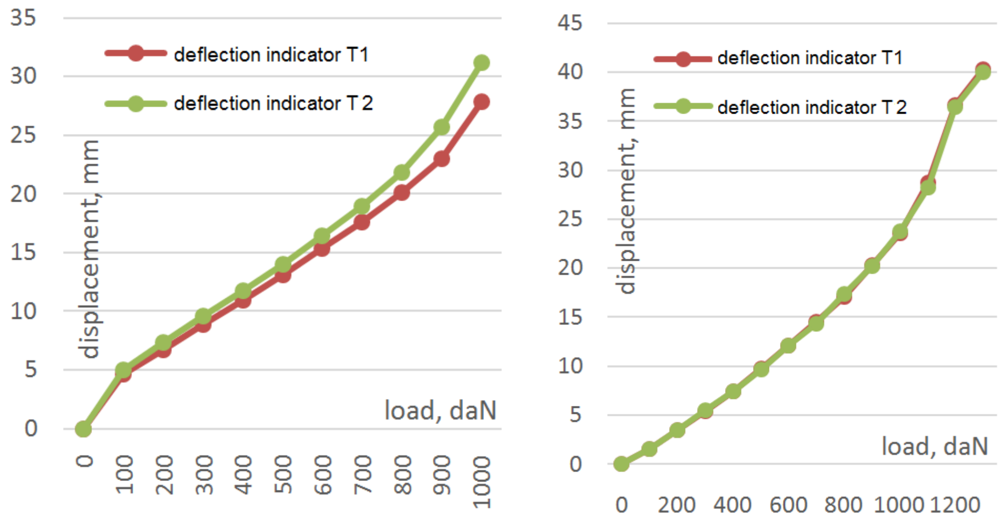


(a) sample №1L(LGSS)

(b) sample №1S(LGSS)

(c) sample №2L(LGSS)

(d) sample №2C(LGSS)



(e) sample №3L(LGSS) **(f) sample №3C(LGSS)**

Figure 4 – The displacements in deflectometer T1 and T2 depending on the applied load values

The test results are summarized in table 3.

As can be seen from table 3, LSCS-based panels have, on average, 38% more load bearing capacity than LGSS-based panels.

Table 3 – General test results

№ of sample	Damage load (force in the Jack), daN (daN /m^2)		Average deflection in the middle of the span at the damage, mm	
	LSCS	LGSS	LSCS	LGSS
1L,1C	1,300 (1,266)	920 (896)	33	21
2L,2C	1,800 (1,753)	1,100 (1,071)	37	25
3L,3C	1,100 (1,071)	1,020 (993)	28	27
Average value	1,400 (1,364)	1,013 (987)	33	24
Critical value	1,100 (1,071)-min	920 (896) - min	37 (max)	27(max)

The behavior and destruction are shown in figures 5-7. All samples were destroyed with the same behavior -in the span under one of the distribution concrete prisms, except for one sample LGSS, which collapsed on the support from the action of the shear force - the support reaction.

Figure 5 – LSCS - slab panel behaviour crush

Figure 6 – LGSS - slab panel behavior crush (case of collapse in the span)

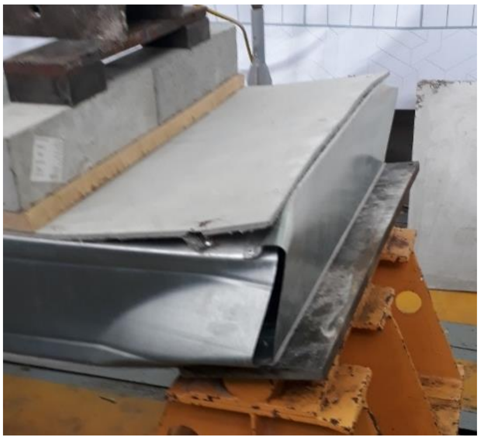


Figure 7 – LGSS - slab panel behavior crush (case of collapse on the support)

4 Discussion

Consider the design model with the GPS-profile (200x50x1.5 mm) on specification of requirements TU 1121-001-87370376-2015 «Roll-formed steel sections» (Russian codes).

The moment of area of a single shelf section in profile $W_{\min} = 26.26$ cm ^{3}.

Moment of inertia of a single section $I = 262.61$ cm ^{4}.

According to the passport for steel and table 6.2.SP 260.1325800.2016 (Russian codes), $R_y = 225$ MPa, $R_{un} = 300$ MPa – yield point and ultimate strength respectively.

In the assumption of considering the structure as only steel material, consider three variants of calculation:

1. Using equivalent load (figure 8).

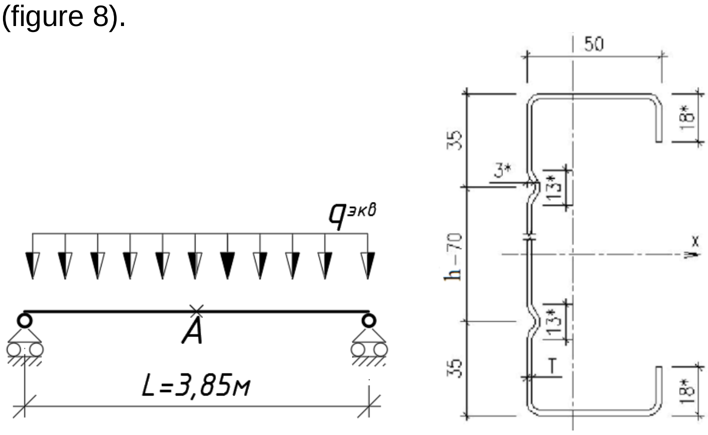


Figure 8 – Design scheme with the equivalent distributed load

Maximum bending moment appears at the point A and equals to:

$$M = \frac{ql^2}{8} \quad (1)$$

From other side, from the strength condition

$$\frac{M}{W_{\min} R_y \gamma_c} \le 1 \quad (2)$$

Bending moment could be expressed as:

$$M = W_{\min} R_y \gamma_c \quad (3)$$

Equating (1) and (3), we get the ultimate distributed load the jacking system

$$q = \frac{8W_{\min} R_y \gamma_c}{l^2} = \frac{8 \cdot 2 \cdot 26.26 \cdot 10^{-6} \cdot 225 \cdot 10^6 \cdot 1{,}0}{3.85^2} = 6{,}378 \text{ N/m=650daN/m} \quad (4)$$

that corresponds to P=834 daN in terms of one jack

2. Using point loads (figure 9).
This design scheme more precisely corresponds to the loading scheme.

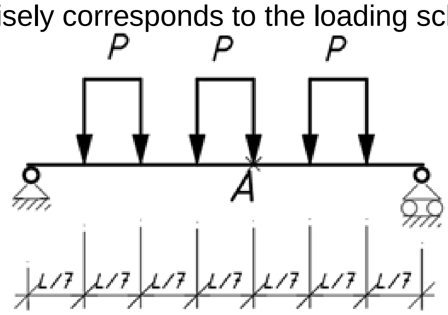


Figure 9 – Design scheme with the point loads

The maximum bending moment appears at point A and from the equilibrium equations equals to:

$$M = \frac{3Pl}{7} \quad (5)$$

Equating (3) and (5), we get the ultimate point load the jacking system (6):

$$P = \frac{7W_{\min} R_y \gamma_c}{3l} = \frac{7 \cdot 2 \cdot 26.26 \cdot 10^{-6} \cdot 225 \cdot 10^6 \cdot 1.0}{3 \cdot 3.85} = 7{,}162 \text{ N} \quad (6)$$

Taking into account the possible participation in fiber cement sheets behaviour and neglecting of any additional (but minor) safe load factors, the results (4) and (6), in general, confirm the experimental data without foam concrete filling

3. Combined action of the shear force and bending moment
As the design load, we take the average breaking load P=1,013 daN and calculate the equivalent stresses in the most critical section, shown in figure 7 by the point A.
Statical cross-sectional moment at the point located at the wall and shelf junction:

$$S = 2 \times 5 \times 0.15 \times (\frac{7}{2} + 3.5 + \frac{0.15}{2}) = 10.6 \text{ cm}^3 \quad (7)$$

Shear force at the point A:

$$Q = 0.5P = 0.5 \times 1{,}013 = 506.5 \text{ daN} \quad (8)$$

Tangential stresses at the most critical cross-section point:

$$\tau_{xy} = \frac{QS}{It_t} = \frac{506.5 \times 5.31}{262.61 \times 0.15} = 68 \text{ daN / cm}^2\text{=6.8 MPa} \quad (9)$$

Normal stresses in the cross section

$$\sigma = \frac{3Pl}{7W_{\min}} = \frac{3 \times 1{,}013 \times 385}{7 \times 2 \times 26.26} = 3{,}182 \text{ daN / cm}^2 = 318 \text{ MPa} \quad (10)$$

Equivalent stress

$$\sigma_{eq} = (\sigma^2 + 3\tau_{xy})^{1/2} = (312^2 + 3 \cdot 7^2)^{1/2} = 313 \text{ MPa} \quad (11)$$

In fact, this stress, provided only by profile steel behavior will be equal to 35 MPa approximately due to the lack of accounting for the own weight of the panel (26daN / m^2) and distribution equipment (260 daN). However, they should be neglected because of the actual inclusion of fiber cement panels in the structure work.

Thus, the damage equivalent stress value was more than the characteristics stated in the quality.

Certificate of the steel grade -yield strength 220 MPa and ultimate strength 300 MPa, which indicates the reliability of the tests, carried out for LGSS samples.

5 Conclusions

1. The researches have shown that the load-bearing capacity (excluding the load of its own weight) of slab panels samples using monolithic foam concrete of average density D400 is 1.20...1.64 times greater than the load-bearing capacity of similar samples without foam concrete filling.
2. Taking into account the foam concrete own weight load, the condition load effect factor of profile steel elements of considering in the paper structure (with particular span and section) as steel (or thin-walled steel) is γ_c=1.25.
3. It has been shown that filling the structure with monolithic foam concrete, including due to the high degree of adhesion, prevents loss of profile steel elements local stability
4. The bearing capacity of the slab in the first group of the ultimate limit state is not less than 1,071 daN/m^2

References

1. Sovetnikov, D.O., Videnkov, N.V., Trubina, D.A. Light gauge steel framing in construction of multi-storey buildings. Construction of Unique Buildings and Structures. 2015. 3(30). Pp. 152–165. DOI:10.18720/CUBS.30.11.
2. Orlova, A.V., Zhmarin, E.N., Paramonov, K.O. Power efficiency of houses from light-gauge steel structures. Construction of Unique Buildings and Structures. 2013. 6(11). Pp. 1–13. DOI:10.18720/CUBS.11.1.
3. Rybakov, V.A., Ananeva, I.A., Rodicheva, A.O., Ogidan, O.T. Stress-strain state of composite reinforced concrete slab elements under fire activity. Magazine of Civil Engineering. 2017. 74(6). Pp. 161–174. DOI:10.18720/MCE.74.13.
4. Bushmanova, A. V., Kharchenko, D.K., Semenov, K.S., Barabanshchikov, Y.G., Korovina, V.K., Dernakova, A. V. Thermal cracking resistance in massive steel-reinforced concrete structures. Magazine of Civil Engineering. 2018. 79(3). Pp. 45–53. DOI:10.18720/MCE.79.5.
5. Nedviga, E., Beresneva, N., Gravit, M., Blagodatskaya, A. Fire Resistance of Prefabricated Monolithic Reinforced Concrete Slabs of “Marko” Technology. Advances in Intelligent Systems and Computing. 2018. 692. Pp. 739–749. DOI:10.1007/978-3-319-70987-1_78.
6. Rybakov, V.A., Al Ali, M., Panteleev, A.P., Fedotova, K.A., Smirnov, A. V. Bearing capacity of rafter systems made of steel thin-walled structures in attic roofs. Magazine of Civil Engineering. 2017. 76(8). Pp. 28–39. DOI:10.18720/MCE.76.3.
7. Ariyanayagam, A.D., Mahendran, M. Fire performance of load bearing LSF wall systems made of low strength steel studs. Thin-Walled Structures. 2018. 130. Pp. 487–504. DOI:10.1016/j.tws.2018.05.018.
8. Bronzova, M.K., Vatin, N.I., Garifullin, M.R. Frame buildings construction using monolithic foamed concrete. Construction of Unique Buildings and Structures. 2015. 1(28). Pp. 74–90.
9. Rum, R.H.M., Jaini, Z.M., Abd Ghaffar, N.H., Abd Rahman, N. A Preliminary Experimental Study on Vibration Responses of Foamed Concrete Composite Slabs. IOP Conference Series: Materials Science and Engineering. 2017. 271(1). DOI:10.1088/1757-899X/271/1/012102.

10. Prabha, P., Palani, G.S., Lakshmanan, N., Senthil, R. Flexural Behaviour of Steel-Foam Concrete Composite Light-Weight Panels. KSCE Journal of Civil Engineering. 2018. 22(9). Pp. 3534–3545. DOI:10.1007/s12205-018-0827-7.
11. Jerman, M., Keppert, M., Výborný, J., Černý, R. Hygric, thermal and durability properties of autoclaved aerated concrete. Construction and Building Materials. 2013. 41. Pp. 352–359. DOI:10.1016/j.conbuildmat.2012.12.036.
12. Ahmadi, A., Mathieson, C., Clifton, G.C., Das, R., Lim, J.B.P. An experimental study on a novel cold-formed steel connection for light gauge open channel steel trusses. Journal of Constructional Steel Research. 2016. 122. Pp. 70–79. DOI:10.1016/j.jcsr.2016.02.007.
13. Hulimka, J., Krzywoń, R., Jędrzejewska, A. Laboratory Tests of Foam Concrete Slabs Reinforced with Composite Grid. Procedia Engineering. 2017. 193. Pp. 337–344. DOI:10.1016/j.proeng.2017.06.222.
14. Kadela, M., Kozłowski, M. Foamed Concrete Layer as Sub-structure of Industrial Concrete Floor. Procedia Engineering. 2016. 161. Pp. 468–476. DOI:10.1016/j.proeng.2016.08.663.
15. Vlcek, J., Drusa, M., Scherfel, W., Sedlar, B. Experimental Investigation of Properties of Foam Concrete for Industrial Floors in Testing Field. IOP Conference Series: Earth and Environmental Science. 2017. 95(2). DOI:10.1088/1755-1315/95/2/022049.
16. Orlovich, R.B., Bespalov, V. V., Derkach, V.N. Compressed-bent masonry walls reinforced with composite materials. Magazine of Civil Engineering. 2018. 79(3). Pp. 112–119. DOI:10.18720/MCE.79.12.
17. Bespalov, V. V., Ucer, D., Salmanov, I.D., Kurbanov, I.N., Kupavykh, S. V. Deformation compatibility of masonry and composite materials. Magazine of Civil Engineering. 2018. 78(2). Pp. 136–150. DOI:10.18720/MCE.78.11.
18. Barabanshchikov, Y., Fedorenko, I., Kostyrya, S., Usanova, K. Cold-Bonded Fly Ash Lightweight Aggregate Concretes with Low Thermal Transmittance: Review. Advances in Intelligent Systems and Computing. 2019. 983. Pp. 858–866. DOI:10.1007/978-3-030-19868-8_84.
19. Usanova, K.Y. Properties of Cold-Bonded Fly Ash Lightweight Aggregate Concretes. Lecture Notes in Civil Engineering. 2020. 70. Pp. 507–516. DOI:10.1007/978-3-030-42351-3_44.
20. Krutilin, A.B., Rykhlionak, Y.A., Liashkevich, V. V. Thermophysical characteristics of low density autoclaved aerated concrete and their influence on durability of exterior walls of buildings. Magazine of Civil Engineering. 2015. 54(2). Pp. 46–55. DOI:10.5862/MCE.54.5.
21. Vatin, N.I., Gorshkov, A.S., Kornienko, S.V. The consumer properties of wall products from AAC. Construction of Unique Buildings and Structures. 2016. 1(40). Pp. 78–101.
22. Alyabyeva, D.A. Reinforcing of large gas-concrete panels from an autoclave. Construction of Unique Buildings and Structures. 2015. 8(35). Pp. 24–35.
23. Samarin, O.D. Temperature in linear elements of enclosing structures. Magazine of Civil Engineering. 2017. 70(2). Pp. 3–10. DOI:10.5862/MCE.70.1.
24. Leshchenko, M. V., Semko, V. Thermal characteristics of the external walling made of cold-formed steel studs and polystyrene concrete. Magazine of Civil Engineering. 2015. 60(8). Pp. 44–55. DOI:10.5862/MCE.60.6.
25. Trubina, D.A., Kononova, L.A., Kaurov, A.A., Pichugin, E.D., Abdulaev, D.A. Local buckling of steel cold-formed profiles under transverse bending. Construction of Unique Buildings and Structures. 2014. 4(19). Pp. 109–127.
26. Kirsanov, A.I., Stolyarov, O.N. Mechanical properties of synthetic fibers applied to concrete reinforcement. Magazine of Civil Engineering. 2018. 80(4). Pp. 15–23. DOI:10.18720/MCE.80.2.
27. Travush, V.I., Konin, D. V., Krylov, A.S. Strength of reinforced concrete beams of high-performance concrete and fiber reinforced concrete. Magazine of Civil Engineering. 2018. 77(1). Pp. 90–100. DOI:10.18720/MCE.77.8.
28. Medvedev, V.N., Semeniuk, S.D. Durability and deformability of braced bending elements with external sheet reinforcement. Magazine of Civil Engineering. 2016. 63(3). Pp. 3–15. DOI:10.5862/MCE.63.1.
29. Kanishchev, R.A. Analysis of local stability of the rectangular tubes filled with concrete. Magazine of Civil Engineering. 2016. 64(4). Pp. 59–68. DOI:10.5862/MCE.64.6.
30. Kikot, A.A. Design of cold-formed tension members using the CFSteel software. Magazine of Civil Engineering. 2016. 61(1). Pp. 42–59. DOI:10.5862/MCE.61.5.

31. Vatin, N.I., Nazmeeva, T., Guslinscky, R. Problems of cold-bent notched c-shaped profile members. Advanced Materials Research. 2014. 941–944. Pp. 1871–1875. DOI:10.4028/www.scientific.net/AMR.941-944.1871.

32. Garifullin, M., Pajunen, S., Mela, K., Heinisuo, M., Havula, J. Initial in-plane rotational stiffness of welded RHS T joints with axial force in main member. Journal of Constructional Steel Research. 2017. 139. Pp. 353–362. DOI:10.1016/j.jcsr.2017.09.033.