Bearing Capacity of Steel-Polystyrene Concrete Slab

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Abstract. The article proposes the construction of a steel-concrete floor. Processes of making, modelling and testing of steel-polystyrene concrete beams and slabs are considered. The results of tests of prototypes are presented. During the tests, the stresses in the steel components of the beams and the deflections value of the plates were measured. The combined action of a thin-walled steel structure and polystyrene concrete is noted. As a result of the combined action of polystyrene concrete and a thin-walled profile, it was possible to more evenly distribute stresses in the metal profile. The destruction of the structure occurred due to the loss of stability of the upper profile belt between the anchoring points. Polystyrene concrete slab is recommended as a roof slab in residential buildings

1. Introduction

Efficient lightweight steel structures have recently been widely used in construction. The most effective use of structures made of galvanized thin-walled roll-formed profiles in seismic regions, low-rise construction, during the reconstruction of buildings, in built-in structures, etc. The use of light steel thin-walled structures (LSTS) allows you to obtain a significant economic effect due to the reduction of dead weight and seismic loads, reducing transport costs, labor costs for installation, reduction of construction time [1,2]. For the manufacture of frames, three types of profiles are used: channel, c-shaped and z-shaped, with a height of 100-350 mm from rolled galvanized steel with a thickness of 0.7-2.0 mm with a yield point of 25-350 MPa and a relative elongation of ≥ 18%. To increase the stiffness of the profiles under local load and torsion, their wall is given a stepped shape during profiling. Increasing the stiffness of a thin-walled profile is possible by placing it in a rigid environment. For example, in lightweight concrete - polystyrene concrete.

Polystyrene concrete is a composite material, which includes Portland cement, silica aggregate, lightweight aggregate, which are expanded polystyrene granules and modifying additives. Its advantages include the possibility of varying density within a wide range, as a result of which polystyrene concrete can be both structural and heat-insulating material. The exceptionally low bulk density of foamed plastic particles allows the production of lightweight concrete with a bulk density, the range of which can be selected in accordance with the requirements of a specific field of application, while the material receives a range of characteristics [3-8]. The durability of polystyrene concrete can be predicted for more than 50 years in low stresses.
It is proposed to use a thermal profile as a bearing element. Thermal profile is a beam with through longitudinal grooves cut in a checkerboard pattern. This significantly increases the heat and sound insulation properties. Perforation allows you to combine the work of profile and concrete. As shown by the results of modeling the C-shaped profile in the ANSYS software package, the working area of the profile is outside the perforation zone. The profile performance is significantly influenced by the profile length and steel thickness.

2. Modeling the combined action
We simulated the interaction of the profile with a different aggregate.

During the tests, the profile was filled with an elastic medium with different modulus of elasticity \( E_0 \). A bonding layer was placed between the metal profile and the elastic medium. Based on the test results, graphs of the dependence of the stresses \( N_y \) and displacements of the beam were plotted depending on the elastic modulus \( E_0 \) (figures 1, 2). The resulting graphs can be conditionally divided into 3 zones: \( E_0: 0÷8000 \text{ kg/cm}^2 \) – conditionally a zone of polystyrene concrete; \( E_0: 8000÷60000 \text{ kg/cm}^2 \) – conditionally a zone of lightweight concrete; \( E_0: 60000÷160000 \text{ kg/cm}^2 \) – conditionally a zone of heavy concrete).

The most effective elastic medium works in the area of polystyrene concrete, because the greatest changes occur in it. So in the zone of lightweight concrete the ratio is \( \sigma / E_0 = 5 \times 10^{-5} \), in the zone of heavy concrete ratio is \( \sigma / E_0 = 5 \times 10^{-6} \). The deflection graphs show the same effect.

The influence of the polystyrene concrete zone on stresses can be described by a linear equation: \( \sigma_{bs} = \sigma_s - E_0 / 12800 \), where \( \sigma_s \) - the stress in a steel beam without an elastic medium.

The change in the elastic modulus of the bonding layer from \( E_0=13 \text{ kg/cm}^2 \) to \( E_0=1500 \text{ kg/cm}^2 \) realistically did not affect the stresses in the metal profile; an increase in the thickness of the bonding layer \( (E_0=13 \text{ kg/cm}^2) \) from 0.1 mm to 5.1 mm, i. e. 51 times, led to an increase in stresses in the polystyrene concrete zone by 13%, in the light concrete zone - by 18%, in the heavy concrete zone - by 26%. De- flexion in the polystyrene concrete zone increased by 11%, in the light concrete zone – by 15%, in the heavy concrete zone-by 14.

A vertical crack was also modeled in the sample with Young's modulus of the medium \( E_0=1500 \text{ kg/cm}^2 \). From the moment of crack initiation until it reached a length of 100 mm, the stresses in the metal shell increased by 18%.

![Figure 1. Graph of the dependence of deflection along the Z axis on the elastic modulus \( E_0 \).](image1.png)

![Figure 2. Graph of the dependence of stresses \( N_y \) on the elastic modulus \( E_0 \).](image2.png)
The simulation results showed the effectiveness of the use of polystyrene concrete to increase the stability of the walls of thin-walled profiles.

Thus, the use of polystyrene concrete and a bent perforated profile for precast floor slabs seems to be a promising and economically feasible task [9-13]. The combined action is ensured by profile perforation and structural reinforcement. Polystyrene concrete ensures the stability of the profile wall, sound insulation and thermal insulation of the slab [14-27]. The resulting board is easy to manufacture and lightweight. An important advantage is the possibility of making slabs directly in the design position on site.

3. Test procedure

The initial characteristics of the slab were studied when testing beams with dimensions of 6000×200×200 mm from two load-bearing C-shaped steel thin-walled roll-formed INSI sections 200 mm high, 50 mm wide and 0.8 mm thick. Two samples were made: without filler and filled with polystyrene concrete. The characteristics of polystyrene concrete used in the work are shown in table 1.

Table 1. Characteristics of polystyrene concrete.

| Average density (kg/m³) | Grade class | Mean compressive strength $R$ (MPa) | Bending tension strength (MPa) | Prism strength (MPa) |
|-------------------------|-------------|------------------------------------|-------------------------------|--------------------|
| D500                    | B2.0        | 2.90                               | 0.60                          | 1.8                |

At the same time, a coating plate with dimensions of 6000 × 1000 × 200 mm was made from six thin-walled bent profiles with a pitch of 200 mm. The beams were fixed at the ends of the coating slab using profiles 1000 × 200 mm in size, and wooden plates 1000 × 150 × 15 mm installed 1.5 m at the top and bottom of the slab using self-tapping screws. The profiles were cleaned and decreased for better adhesion of concrete to the profile metal (Figure 3).

It should be noted that preliminary comparative experiments were carried out on beams and slabs using polystyrene concrete and foam concrete having the same strength and close density. The supporting profiles were 200 mm high and had no perforations. As a result, conclusions were drawn about the need to perform perforations in the profiles and to abandon foam concrete.

Similar results were obtained when modeling beams on a computer using the LIRA software package. The calculation results were obtained in the form of isofields of deflection and stress distributions (figures 4 and 5).

From the above design results on the LIRA software package, it can be seen that the deformation diagram and stress distribution in the general case corresponds to the data obtained experimentally: the main deformations occur on the upper flange, which leads to the loss of stability of the entire profile. In the future, by changing the parameters of the filler, it is possible with sufficient accuracy to use the LIRA software package to design real structures with fillers from various materials.
Figure 3. Slabs making process.

Figure 4. Isofields of distribution of deflection and stresses in samples without filler.

Figure 5. Isofields of distribution of deflection and stresses in specimens filled with concrete.
The structures were installed on metal frames. Uniform loading of structures was carried out with metal pipes or blocks filled with concrete, each weighing 40 kg. The deformations of the profiles were measured with strain gauges based on 100 mm and deflectors with a scale division of 0.01 mm (diagrams in figure 6).

**Figure 6.** Layout of strain gauges and deflection meters on a slab with foam concrete.

The load was applied in steps of 160 kg, with holding at each loading step for 15 minutes (figure 7). Loading was carried out until the appearance of obvious signs of loss of stability of the C-shaped profiles (loss of stability of the shelf or buckling of the wall). After each loading, measurements were taken and an analysis of the state of the structure was carried out.

**Figure 7.** Slab loading.

### 4. Research results

Up to a payload of 506 kg/m², the slab worked resiliently. At the next step, the side profiles in the slab began to move away from the concrete, lose stability in the compressed zone, and at the places where the concentrated load was applied, detachment and buckling began. Failure of the structure occurred with a payload of 560 kg/m² with a simultaneous loss of stability of the compressed zone of the profiles and crushing of the concrete in the compressed zone. Beam deflections (left), the results of measurements by sensors on the slab (right) are shown in figure 8.
Analysis of the results showed:
1) the stretched zone in the steel thin-walled profile works stably - the stresses increase in proportion to the load up to the yield point;
2) the upper compressed flange of the profile does not work evenly - after reaching 40-60% of the breaking stress, signs of loss of stability appear;
3) the wall of the profile works stably until the moment of loss of stability of the upper compressed flange, after which the stresses in the wall from compression increase sharply, and the wall loses its stability;
4) filling the slabs with polystyrene concrete leads to a uniform stress distribution. In case of destruction, the edge loses its stability at higher loads, as in a slab filled with heavy concrete, but with a lower weight of the beams themselves;
5) filling the slabs with polystyrene concrete does not give the expected uniform distribution of stresses, loss of stability occurs in the compressed zone due to the absence of anchorage of the profile, which does not ensure their joint work.

5. Conclusion
In total, samples of several series were manufactured and tested. Analyzing the obtained experimental data and the graphs built on their basis, the following conclusions can be drawn:
1) the destruction of the polystyrene concrete slab with load-bearing steel thin-walled profiles was due to the loss of stability of the upper profile flange due to the absence of its anchorage in concrete, the wall and the lower profile flange worked stably until destruction, with low stresses;
2) the loss of stability of the upper flange occurred at a distance of about 1/3 from the edge of the flange;
3) the improvement of the work of the compressed zone of the structure is achieved by additional anchoring of the profile with self-tapping screws (or by using a special profile with anchoring in the compressed zone) or by making a thin-walled screed made of strong concrete in the compressed zone;
4) the stability of the bent profile is ensured (local stability of the upper belt) when filled with polystyrene concrete (slightly worse with foam concrete).

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