A Study of Sandwich Reinforced Concrete – Foamed Concrete Floor Slabs

Justyna Sobczak-Piąstka 1, Oksana Lytvyniak 2, Andrii Kramarchuk 3, Borys Ilnytskyy 3, Yuriy Famulyak 4

1 UTP University of Science and Technology, Faculty of Civil and Environmental Engineering and Architecture, Al. prof. S. Kaliski street, 7, 85-796 Bydgoszcz, Poland
2 Lviv Polytechnic National University, Department of Civil Safety, S. Bandera street, 12, 79013 Lviv, Ukraine
3 Lviv Polytechnic National University, Department of Building Constructions and Bridges, S. Bandera street, 12, 79013 Lviv, Ukraine
4 Lviv National Agrarian University, Faculty of Civil Engineering and Architecture, 80381, V. Velykoho street, Dublyany, Zhovkva district, Lviv region, Ukraine
justynas@utp.edu.pl

Abstract. The development of housing construction demands an application of building materials which ensure necessary functional performance of structures, have high heat-insulating properties, are environmentally friendly and their use is economically appropriate. Simultaneous ensuring of mentioned indices is possible because of complex combined joining of building materials with different physical-mechanical properties. This article presents experimental determination of useful load for sandwich reinforced concrete – foamed concrete floor slabs. Sandwich reinforced concrete – foamed concrete floor slabs are the floor slabs which are composed of normal concrete, non-autoclaved foamed concrete and spatial reinforcement frame. Experimental determination of useful load was carried out on series that compose of four sandwich reinforced concrete – foamed concrete floor slabs. Experimental test of sandwich reinforced concrete – foamed concrete floor slabs was carried out under condition of pure bending that was achieved by applying to floor slab in one third of its span two concentrated forces equal in magnitude. Useful load for sandwich reinforced concrete – foamed concrete floor slabs was 33.23÷77.87 kN/m². Sandwich reinforced concrete – foamed concrete floor slabs are proposed to be used in construction of housing and social structures.

1. Introduction

The development of housing construction demands an application of building materials which ensure necessary functional performance of structures, have high heat-insulating properties, are environmentally friendly and their use is economically appropriate [1, 2]. Simultaneous ensuring of the mentioned indices is possible due to the complex, combined joining of building materials with different physical and mechanical properties. The building materials of this kind are traditional materials such as normal concrete and reinforcement rod, and also modern materials as cellular concretes, especially foamed concrete.

The scientific attention to the foamed concrete is caused by the fact that this building material is characterized the low self-mass, well heat-insulating and soundproofing properties, fire resistance [3,
Each year, the number of scientific investigations of foamed concrete is increased. It worth be noted that the scientists carried out the researches of physical and mechanical properties of foamed concrete [5-7], the fire resistance of foamed concrete [8], the investigations of foamed concrete as a material for the road construction [9], the study of foamed concrete bricks [10] and etc. However, the researches of non-autoclave foamed concrete floor slabs were carried out sufficiently small, because the researches of non-autoclave foamed concrete has low compression strength. In our opinion, this scientific problem can solve by means of a joining up the normal concrete, the non-autoclave foamed concrete with basic and additional reinforcement by reinforcement rod and propylene fiber [11,12]. This action will permit to ensure the receiving the appropriate functional characteristics of floor slabs with the simultaneous considerable decrease of its construction mass.

The practical use of building structures made of different structural materials is only possible due to the availability of reliable information about loading which can be perceived by this structure. The simulation of the stress-strain state of complex structural elements that occurs during exploitation of structures is one of the urgent tasks of scientific investigations. The aim of this research is to experimentally determine the effect of useful load on the load-bearing capacity of sandwich reinforced concrete – foamed concrete floor slabs which are composed of normal concrete, foamed concrete and reinforcement rod.

2. Materials and Methods

Sandwich reinforced concrete – foamed concrete floor slabs are the floor slabs, which are composed of normal concrete, non-autoclaved foamed concrete and spatial reinforcement frame (figure 1) [13, 14].

![Figure 1. Sandwich reinforced concrete – foamed concrete floor slab: (1) – spatial reinforcement frame; (2) – normal concrete; (3) – non-autoclaved foamed concrete](image)

Experimental determination of useful load, which takes by sandwich reinforced concrete – foamed concrete floor slabs, was carried out on series that compose of four slabs – FSS-1.1, FSS 1.2, FSS-2.1, FSS-2.2. The geometrical sizes of slabs are shown on figure 1.

Each of sandwich floor slabs was composed of normal concrete (strength quality of concrete was 22÷25 MN/m²) and structurally identical spatial reinforcement frame (strength quality of reinforcement was 380÷400 MN/m²). Sandwich reinforced concrete – foamed concrete floor slabs FSS-1.1 and FSS 1.2 were composed of non-autoclaved foamed concrete of density D800 with additional reinforcement...
by polypropylene fiber and sandwich reinforced concrete. Foamed concrete floor slabs FSS-2.1 and FSS 2.2 were composed of non-autoclaved foamed concrete of density D1000.

The height of normal concrete in sandwich reinforced concrete – foamed concrete floor slabs was 40 mm, and the height of non-autoclaved foamed concrete was 160 mm.

The process of manufacturing of sandwich reinforced concrete – foamed concrete floor slabs is carried out two stages. On the first stage, framework slabs are produced in the building constructions factory. These framework slabs are created of normal concrete and spatial reinforcement frame. On the second stage, framework slabs are mounted on building edifice closely one by one. After that, the top parts of sandwich reinforced concrete – foamed concrete floor slabs are concreted by foamed concrete. This process of manufacturing allows receiving a solid structure of floor slab. It worth be noted that the layer of normal concrete and spatial reinforcement frame carries out the function of the desk form for a layer of foamed concrete [13].

Experimental test of sandwich reinforced concrete – foamed concrete floor slabs was carried out under condition of pure bending that was reached by loading to floor slabs in third parts of slab’s span by two concentrated forces (figure 2).

![Figure 2. Experimental test of sandwich reinforced concrete – foamed concrete floor slabs](image)

The total load for experimental slab was created by hydraulic jack. It was loaded with intervals discretely by appropriate stages. Symmetry of distribution of total load was ensured by distributive cross-arm. Accordingly concentrated load, which was imposed in third part of slab’s span, was equal to half of total load, which was created by hydraulic jack [13].

Accepted scheme of loading, by experimental evaluation of deflected mode of floor slab, represents the most adverse conditions of load that permit to guarantee bearing capacity of sandwich reinforced concrete – foamed concrete floor slabs (with high level of reliability) by its use in building structures by appropriate values of two concentrated limit forces, which were placed in third part of slab’s span. However, in real building structures predominantly distributed load influence on floor slabs, but to determine experimentally its limit value in laboratory conditions or by full-scale tests of floor slabs are
very difficult, with regard to imposing material consumption for realization of appropriate scheme of loading. Moreover, it is necessary to underline that regulations for different kind of structures are established admissible useful load (distributed), which often are sufficiently used by design of building [15]. Accordingly, it is necessary to develop the empiric determination technique of expected value of limit distributed load on the basis of experimental determination of bearing capacity of floor slab on conditions that pure bending, which is created by two concentrated forces, for full evaluation of predictable bearing capacity of structurally compound sandwich reinforced concrete – foamed concrete floor slabs.

3. Results and discussions

The executed studies permitted to determine the following features in the work of sandwich reinforced concrete – foamed concrete floor slabs. The creation of the first cracks in floor slabs took place on the lower side of floor slab. The step of transversal cracks on the lower side of normal concrete coincided with the step of structural transverse reinforcement, which joined lower longitudinal reinforcement bars. The first cracks on the lateral faces of experimental samples appeared when the loading was increased. Later on, we observed the opening of cracks, the appearance of new cracks and, of course, the increase of the deflection for floor slabs.

Executed experimental tests of sandwich reinforced concrete – foamed concrete floor slabs were allowed to receive such value of limit parameters: concentrated force of destruction - \( N_u \), destructive moment of bending – \( M_u \), and maximum flexure by destruction of slab – \( f_u \) (table 1).

### Table 1. Experimental values of destructive loading of sandwich reinforced concrete – foamed concrete floor slabs

| Model of slabs | Destructive concentrated force of slab \( N_u/2 \), [kN] | Destructive moment of bending \( M_u \), [kN·m] | Maximum flexure by destruction of slab \( f_u \), [cm] |
|----------------|---------------------------------------------------|---------------------------------|-------------------|
| FSS-1.1        | 13.0                                              | 8.23                            | 5.64              |
| FSS-1.2        | 15.5                                              | 9.82                            | 6.43              |
| FSS-2.1        | 29.0                                              | 18.37                           | 13.93             |
| FSS-2.2        | 26.0                                              | 16.47                           | 11.4              |

Limit parameters of destruction of sandwich reinforced concrete – foamed concrete floor slabs, which were experimentally determined, were directly used for calculation values of its corresponding equivalent evenly distributed load (table 2).

### Table 2. The values of equivalent evenly distributed loads for sandwich reinforced concrete – foamed concrete floor slabs

| Model of slabs | Destructive moment of bending \( M_u \), [kN·m] | Equivalent evenly distributed loads by destruction of slab \( d_u^{equiv} \), [kN/m²] |
|----------------|---------------------------------|-----------------------------------|
| FSS-1.1        | 8.23                            | 36.49                             |
| FSS-1.2        | 9.82                            | 43.51                             |
| FSS-2.1        | 18.37                           | 81.40                             |
| FSS-2.2        | 16.47                           | 72.98                             |

Equivalent evenly distributed load (figure 3) was determined by formulas that were received after comparison of expressions, by which were determined the squares of bending moments area that arise
in third part of slab’s span by action of equal concentrated forces (formula (1)) and by action of distributed load (formula (2)) [16]:

\[ M'^{'} \Sigma = \frac{1}{2} q_u^{equiv} \cdot l^2 \cdot \left[ \frac{1}{2} \cdot l^2 - \frac{1}{3} \cdot l^3 \right] = \frac{1}{6} q_u^{equiv} \cdot l^3 \]

\[ M''^{'} \Sigma = 2 \cdot \left( \frac{1}{2} \cdot \frac{N_u}{2} \cdot a^2 \right) + \frac{N_u}{2} \cdot a \cdot (l - 2 \cdot a) = \frac{N_u}{2} \cdot a \cdot l - a^2 \] \[ q_u^{equiv} - \text{equivalent evenly distributed loads by destruction of sandwich reinforced concrete – foamed concrete floor slabs.} \]

After collation of expression (1) and (2) and execution of mathematical cancellation, we received formula (3):
By designing of floor slabs, important meaning has useful load, which are presented for sandwich reinforced concrete – foamed concrete floor slabs in Table 3.

Table 3. The useful load for sandwich reinforced concrete – foamed concrete floor slabs

| Model of slab | \( q_{u}^{equiv} \), kN/m\(^2\) | \( g_s \), kN/m\(^2\) | \( g_c \), kN/m\(^2\) | \( f_{fc} \), kN/m\(^2\) | \( f_r \), kN/m\(^2\) | \( g_{k(u)} \), kN/m\(^2\) |
|---------------|------------------|----------------|----------------|----------------|----------------|----------------|
| FSS-1.1       | 36.49            | 0.24           | 0.91           | 1.29           | 0.82           | 33.23          |
| FSS-1.2       | 43.51            | 0.24           | 0.91           | 1.29           | 0.82           | 40.25          |
| FSS-2.1       | 81.40            | 0.24           | 0.91           | 1.57           | 0.82           | 77.87          |
| FSS-2.2       | 72.98            | 0.24           | 0.91           | 1.57           | 0.82           | 69.45          |

In the table 3:
- \( g_s \) - proper weight of spatial reinforcement frame;
- \( g_c \) - proper weight of normal concrete;
- \( f_{fc} \) - proper weight of non-autoclaved foamed concrete;
- \( g_f \) - proper weight of floor (cement-sand cushion and parquet);
- \( g_{k(u)} \) - useful load for sandwich reinforced concrete – foamed concrete floor slabs by its destruction, which was determined according to (4) [17]:

\[
g_{k(u)} = q_{u}^{equiv} - g_s - g_c - f_{fc} - g_f. \tag{4}
\]

According to the table 3, useful load for sandwich reinforced concrete – foamed concrete floor slabs were \(33.23 ÷ 77.87\) kN/m\(^2\). We recommend to use these floor slabs in housing and social construction for useful load more \(2\) kN/m\(^2\), and also in other buildings, in which useful load for ceiling do not exceed \(10\) kN/m\(^2\).

4. Conclusions
Sandwich reinforced concrete – foamed concrete floor slabs are proposed to use by building of structures of housing and social construction. The useful load for these floor slabs has to be \(2 ÷ 10\) kN/m\(^2\).

Combined use of normal concrete, non-autoclaved foamed concrete and reinforcement rod in floor slabs permit to guarantee high requirements of energy-saving, economy and ecological compatibility, but without deterioration of functional performances of floor slabs.

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