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Stability of light steel thin-walled structures filled with lightweight concrete

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Abstract. The article presents the results of stability calculation of reinforced concrete columns using light steel thin-walled structures investigation. Two steel thin-walled profiles of type "C" or "Σ" were used as the steel shell of such columns. The profiles were combined in the form of a box section with bolts. To increase the stability of the shell, the inner cavity was filled with concrete with lightweight aggregates. Technique of steel thin-walled elements stability calculation with consideration of concreting and joint work of the whole structure involves two types of calculation: for central compression and for joint action of compression and uniaxial bending. To verify the analytical calculations, a computer simulation was performed, which proved the correctness of the theoretical calculations and made it possible to clearly observe the different forms of column stability loss at different coefficients of overload. It was found that the increase of bearing capacity due to the thickness of the profile varies within 2-10%. For smaller profiles this difference is significant (10-23%), and for larger profiles - smaller (5-8%). This is due to the complexity of the manufacturing technology and the cost of materials.

1. Introduction

In the global construction practice one of the most effective structures is reinforced concrete with rigid armature [1]. The most common are compressed elements, such as columns, individual compressed elements of farms or frames, columns of road signs [2], etc. One of the disadvantages of such structures is their relatively large weight. This leads to the improvement of traditional structures, the emergence and implementation of complex reinforced concrete structures of reduced weight.

2. Analysis of recent research and publications

In order to reduce the cost of construction, the functions of load-bearing structures (providing of load-bearing capacity) are sometimes combined with the functions of enclosing structures (providing of thermal conductivity). It is this factor that leads to the improvement of the traditional structures' characteristics, causes the emergence of complex reinforced concrete structures of increased lightness. In figure 1 are shown the examples of lightweight concrete using in low-rise construction [3].



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To create such lightweight concrete structures, it is proposed to reinforce lightweight steel thin-walled cold-formed constructions (LSTC) with lightweight concrete. Calculation of strength and rigidity of reinforced concrete structures is performed according to the general methods of building structures design. However, taking into account the peculiarities of calculating LSTC and their compatible work with lightweight concrete, this issue needs detailed study [4-6].

In connection with the development of computer technology and its broad technical capabilities, to study the stress-strain state of building structures and its individual elements handy with help using finite element analysis software [7].

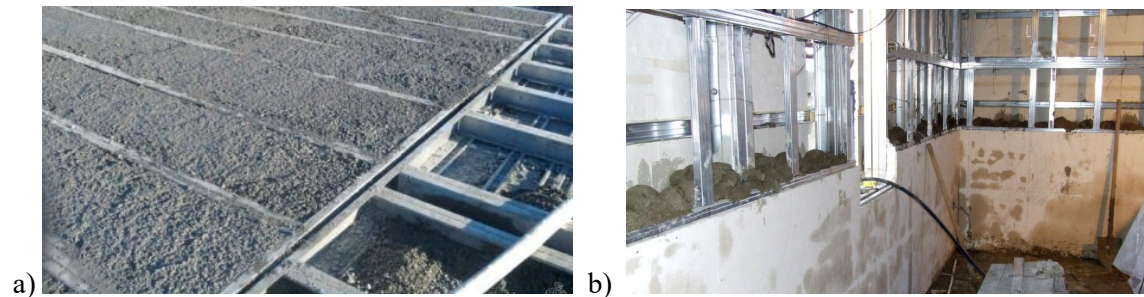


Figure 1. Exploitation of lightweight reinforced concrete in low-rise construction: a) placing overlapping; b) enclosing wall-bearing structures.

3. Formulations of the article's goals

The purpose of the work is to highlight the results of reinforced concrete columns stability calculation using LSTC filled with lightweight concrete: based on the equations of rigidity and conditions of compatibility strains to show dependencies for determining the load limit at the moment of column's failure; to compare the results with the computer simulation the last by the finite element method.

4. The main material with the justification of new scientific results

4.1. General characteristics of the investigated reinforced concrete columns using LST

The investigated lightweight reinforced concrete column consists of a steel shell, a concrete core and connecting bolts (see figure 2). The shell consists of two channel-shaped steel thin-walled profiles of type "C" or " Σ ", combined in the form of a box section. Profiles are connected by bolts. In the formed cavity is placed a reinforcing frame and a concrete mixture with a light aggregate (polystyrene), which is compacted by deep vibrators. Steel profiles play the role of external reinforcement of the structure, fixed formwork and protection of concrete. This concrete core increases the local and general structural stability. If use steel fittings, that increases the load-bearing capacity of the column.

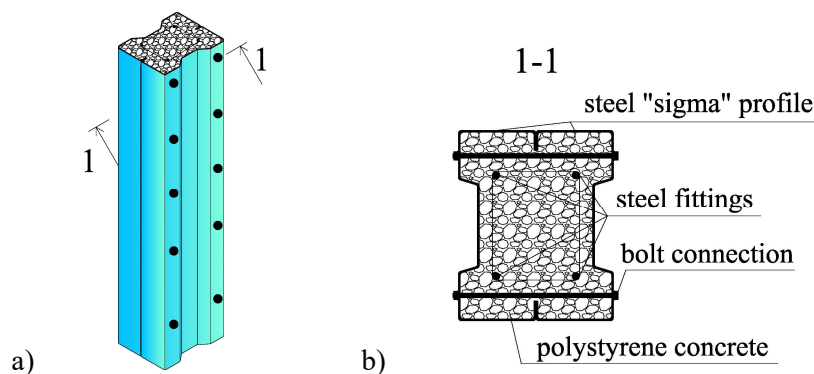


Figure 2. Lightweight reinforced concrete column using LSTC: a) general view; b) cross-section.

4.2. Algorithm of analytical calculations of light steel-concrete columns with LSTC load bearing capacity

Bearing capacity of columns from axial compression will be ensured, if the condition (1) is satisfied.

$$\frac{N_{Ed}}{\chi \cdot N_{pl,Rd}} \leq 1 \quad (1)$$

In the formula (1) N_{Ed} – estimated value of the longitudinal force elements under axial compression; $N_{pl,Rd}$ – bearing capacity of reinforced concrete element in plastic stage (is determined according to the recommendations set out in [3]);

χ – the lowering coefficient for the relevant shape of the stability loss specified in EN 1993-1-1, 6.3.1.2 and dependent on the corresponding conditional flexibility.

The bearing capacity of the column under the combined action of axial compression and uniaxial bending will be ensured if the condition (2) is satisfied.

$$\frac{M_{Ed}}{M_{pl,N,Rd}} = \frac{M_{Ed}}{\mu_d \cdot M_{pl,Rd}} \leq \alpha_M \quad (2)$$

In the formula (2) M_{Ed} – the largest of the moments in two planes and the highest bending moment within the column length;

$M_{pl,N,Rd}$ – the plastic moment of the inner pair of forces, taking into account the longitudinal force N_{Ed} ; $M_{pl,Rd}$ – the plastic moment of the inner pair of forces, defined on the schedule (see figure 3);

μ_d – lowering coefficient;

α_M – coefficient accepted for steel grades S235-S355 $\alpha_M=0.9$, and for steel grades S420-S4605 $\alpha_M=0.8$.

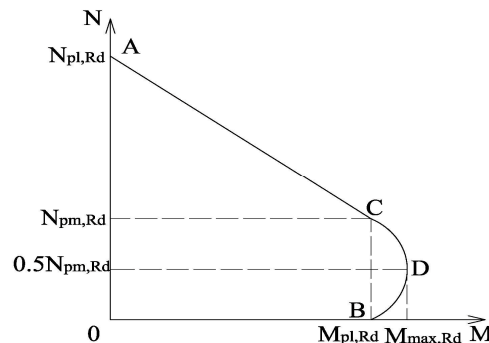


Figure 3. The interaction curve for the combined action of axial compression and uni-axial bending.

The load-bearing capacity of the concrete core is characterized by a volumetric stress state that arises under pressure in a steel cylindrical shackle. Moreover, lightweight concrete has a triple function: perceives external loads, provides overall stability of the steel profile, enhances the steel casing, limits the loss of local stability in the middle of the cross section of the structure. The calculation of the steel shell of cylindrical sheet steel should take into account the loss of resistance of the cylindrical shell to the yield strength of steel, which significantly reduces the strength of such elements.

Consider the load-bearing capacity of a profile that is inside lightweight concrete to increase the load-bearing capacity of the entire element. Considering the nature of the destruction of the three-component lightweight concrete samples, which describe the loss of overall profile stability, it can be assumed that the thin-walled profile is included in the work of the entire cross-section of the element. Reinforced polystyrene eliminate the loss of local stability even the thinnest profile, so the definition of effective area the latter is not required.

4.3. Numerical study of structures by finite element method

The numerical simulation of the experimental samples was performed in the NASTRAN Femap 10.1.1 SC 64bit software (Demo). The dimensions of finite elements are selected according to four indicators: the number of finite elements, the number of nodes of finite elements, the maximum stresses, the time required for the calculation [8 – 9]. The decision was made to break the volume model of concrete into hexahedra with a side size of 10 mm, which is 2.5% of the height of the sample. It was necessary to merge the finite element matching nodes into a single monolithic body [10]. Physico-mechanical characteristics of the materials were given in the form of diagrams and values obtained experimentally.

As a result of the finite element analysis of models of reinforced concrete racks made of light steel thin-walled structures filled with lightweight concrete with polystyrene filler, the forms of general stability loss at different degrees of loading were obtained (see figure 4), as well as distribution of local stress concentrators and local loss of resistance (see figure 5).

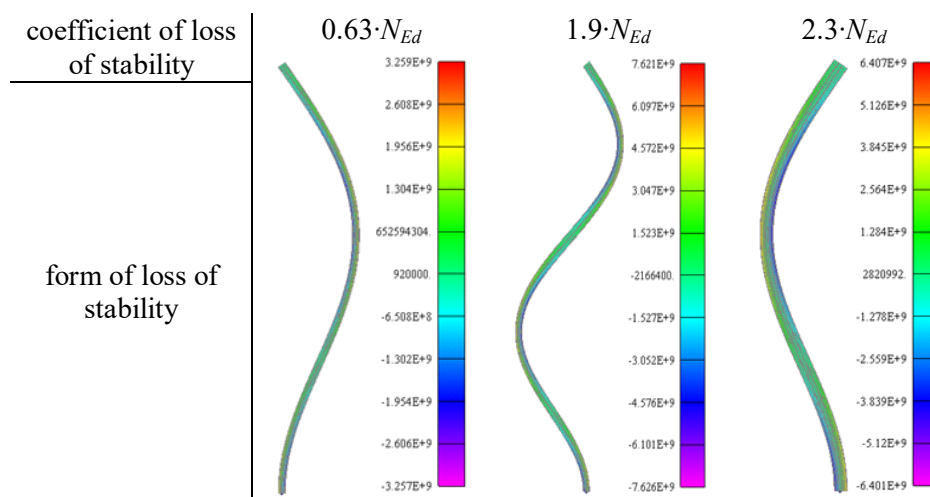


Figure 4. Form loss of overall stability of the models with a shell from a type profile $\Sigma 150$.

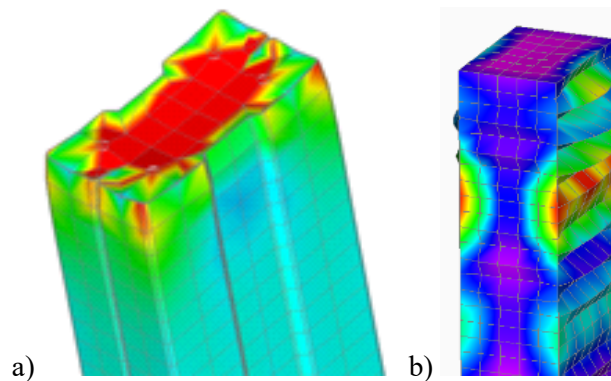


Figure 5. Local stress concentration at the head of reinforced concrete rack model:
a) in concrete core; b) in steel profile shell.

The results of the analytical and numerical calculation of the critical force values at which the stability of reinforced concrete columns of three sizes occurs, are given in table 1.

The results of the numerical simulations confirm the experimental studies (the discrepancy determined by the statistical analysis of the obtained results does not exceed 9.5%), which indicates the reliability of the refined theoretical calculation method and the possibility of using the numerical simulation in the study of light steel structures.

Table 1. The results of analytical and numerical calculations of critical force values.

The name of the columns	Estimated value of longitudinal force N_{ed}	Plastic resistance of cross section N_{plRd}	Value of longitudinal force (numerical experiment)	Stability loss coefficient (numerical experiment)	Percentage of stock
	kN	kN	kN	–	%
$\Sigma 100 \times 1.0$	151.74	238.71	183.81	0.77	21.13
	154.98	238.71	322.26	1.35	–
	164.71	238.71	539.48	2.26	–
$\Sigma 150 \times 1.0$	135.72	301.09	189.69	0.63	39.76
	138.50	301.09	572.07	1.90	–
	151.01	301.09	692.51	2.30	–
$\Sigma 200 \times 1.5$	380.97	668.36	561.42	0.84	47.37
	418.47	668.36	1002.5	1.50	–
	428.82	668.36	1670.9	2.50	–

5. Conclusion

The proposed composite design is effective. Lightweight thin-walled steel shell and concrete core with a light polystyrene work together at all loading levels. The difference between the critical (obtained by numerical calculation) and the calculated (obtained by analytical) value of forces indicates the stock of bearing capacity of the columns, that for profiles $\Sigma 100 \times 1.0$ is 21%, for $\Sigma 150 \times 1.0$ – 40%, for $\Sigma 200 \times 1.5$ – 47%. The coefficient of safety margin is greatest at rigid nodes of fastening of elements.

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