APPLICATION OF LATTICE COMPOSITE STRUCTURES AS REINFORCING ELEMENTS OF CONCRETE COLUMNS

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Abstract

The paper is concerned with the problem of the reinforcement of traditional concrete columns with anisogrid composite lattice structures which consist of continuous unidirectional composite ribs made by wet filament winding. Load-carrying capacity and stiffness of a concrete column with composite lattice reinforcement is studied experimentally and compared with the corresponding characteristics of a concrete column without reinforcement and a traditional concrete column reinforced with steel. Numerical simulation of stress-strain state of the concrete reinforced with composite lattice structure is presented.

1. Introduction

Traditional reinforcement of concrete columns, with steel structural elements which prevents the concrete failure under tension and bending, has reached by now the maximum possible efficiency to increase the load-carrying capacity of concrete construction elements. The possibility to change steel to composite materials are widely discussed now in application to concrete columns [1-3]. The relative number of publications on the application of composites in concrete structures to the total number of publications in civil engineering increased from 0,5% in 2009 to 3,5% in 2014 [4]. Based on the available publications, the following classification of the existing methods of concrete columns reinforcement can be presented:

1. Dispersed reinforcement with nano- and micro-particles.
1.1. Fiber reinforced concrete.
1.2. Concrete reinforced with composite armature.
1.3. Hybrid concrete structure reinforced with both metal and composite elements.
2. External composite reinforcement for newly built or to improve the existing columns.
2.1. Discrete reinforcing frame.
2.2. Integral reinforcing shell.
3. Reinforcement with macro-structural elements.
3.1. Metal armature.
3.2. Composite armature.
3.3. Hybrid armature.

Dispersed reinforcement of concrete and external reinforcement of columns with composite ribs or continuous shells mainly used to repair damaged concrete columns are not considered in this paper.
The application of composite reinforcement instead of metal usually involves the selection of the composite armature geometry and results in the traditional for metals schemes of reinforcement which do not lead to a significant increase in the load-carrying capacity of concrete structures.

The paper is concerned with the development of new structural composite elements allowing us to increase dramatically the load-carrying capacity of concrete column structures. As the basic structure, it is proposed to use the concrete column, reinforced with anisogrid lattice composite structures

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(integral composite reinforcing frame), developed in the Russian Central research institute of special machinery in application to aerospace technology and currently successfully used for production of rocket and space structures for Russian Space Programs [5-9]. Reinforcement of concrete columns with anisogrid composite structure allows us to predict a significant improvement of the structure load-carrying capacity without increasing the cross-sectional dimensions and weight.
Anisogrid composite lattice structures, consisting of systems of helical, circumferential and (if necessary) longitudinal ribs made of unidirectional composite materials by continuous automatic winding, possess extremely high specific (with respect to density) strength and stiffness. Glass, basalt or carbon fibers used to fabricate lattice anisogrid structures are characterized also with higher corrosion resistance and fatigue strength in comparison with traditional steel reinforcing armature. Typical lattice composite structural elements that can be used to reinforce concrete columns are shown in Fig.1.

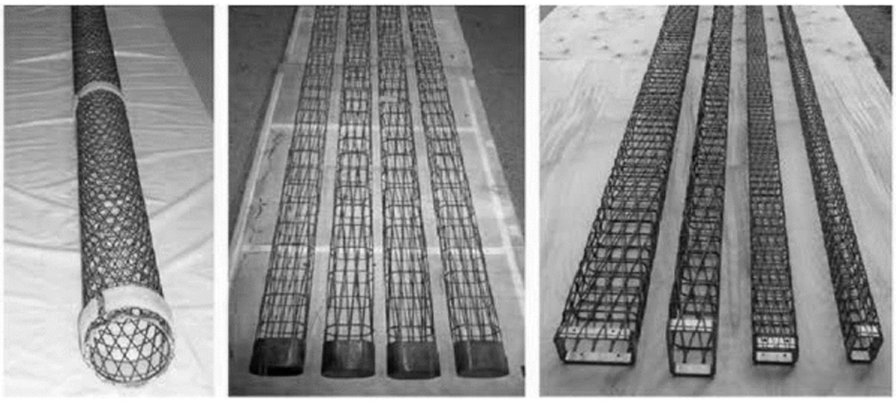
(a) (b) (c)

Figure 1. Anisogrid composite lattice beam-type structures with circular (a), oval (b) and rectangular (c) cross sections.

2. Object of investigation and methods

To confirm the proposed concept, experimental study and finite element analysis of concrete-composite columns reinforced with an anisogrid lattice structure have been undertaken.

2.1. Experimental study of the load-carrying capacity

Within the framework of the Program, 3 concrete columns (C-1, C-2 and C-3) have been designed and fabricated for experimental investigation.
Column C-1 is made of concrete B30 and have no reinforcements. For the normal limit of concrete compressive strength (36 MPa), the load-carrying capacity of the column under axial compression can be found as 0.804 MN.
Column C-2 reinforced with standard steel armature (class AIII 25G2S). Reinforcing frame consist of four 12 mm diameter bars overwrapped with Bp1 helical steel wire with diameter 4 mm and spacing between the wires 0.24 m. The analysis of the column by traditional method [10] gives the failure load under axial compression 1.51 MN.
Column C-3 (concrete-composite column [11]) reinforced with anisogrid lattice structure made of HTS carbon fibers and epoxy resin EHD-MD (Fig. 2). Anisogrid structure has a circular cross section and the following geometrical parameters: length 2.6 m; radius 0.1 m; angle of helical ribs with respect to the axis 15^{o}; the number of symmetric pairs of helical ribs 24; thickness of the lattice structure 5.0 mm; width of the helical rib cross section 5.0 mm; width of the hoop rib cross section 2.0 mm. Modulus of elasticity of the rib material 90 GPa, tensile and compressive strengths –

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1430 MPa and 650 MPa, respectively; rib density 1450 kg / m^3. Theoretical failure load for the lattice structure under axial compression [12] is 0.54 MN. The mass of the lattice structure is 3.6 kg.

Figure 2. Anisogrid lattice composite reinforcement of C-3 Column.

C-1, C-2 and C-3 columns with diameter 0.214 m and length 2.6 m have been subjected to axial compression [13]. The obtained test results are presented in Table 1.

Table 1. Test Results for Experimental Columns C-1, C-2 and C-3

Column	Weight, kg	The ultimate axial force, MN	Axial stiffness, kN / mm
C-1	249.6	0.804	117.5
C-2	255.9	1.46	225.0
C-3	247.5	1.88	224.9

Failure modes for columns C-2 and C-3 are shown in Fig. 3 and 4.

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Figure 3. Failure mode of the column C-2 with steel reinforcement.

Figure 4. Failure mode of the column C-3 with anisogrid lattice composite reinforcement.

As follows from the obtained results, the column C-3 with the composite reinforcement whose weight is 3.3% lower than steel reinforced column C-2 has practically the same stiffness and 26% higher strength.

2.2 Numerical analysis

Stressed state of concrete-composite column C-3 has been undertaken with the aid of finite-element method. Helical and circumferential ribs of the composite lattice structure are simulated with plate elements, whereas tetra-solid elements has been used to simulate concrete. The friction between the anisogrid structure and concrete is ignored. Stressed state of the structure under axial compression is presented in Fig.5. As can be seen, maximum stresses act at the end zone of the column which corresponds to the failure mode in Fig. 4.

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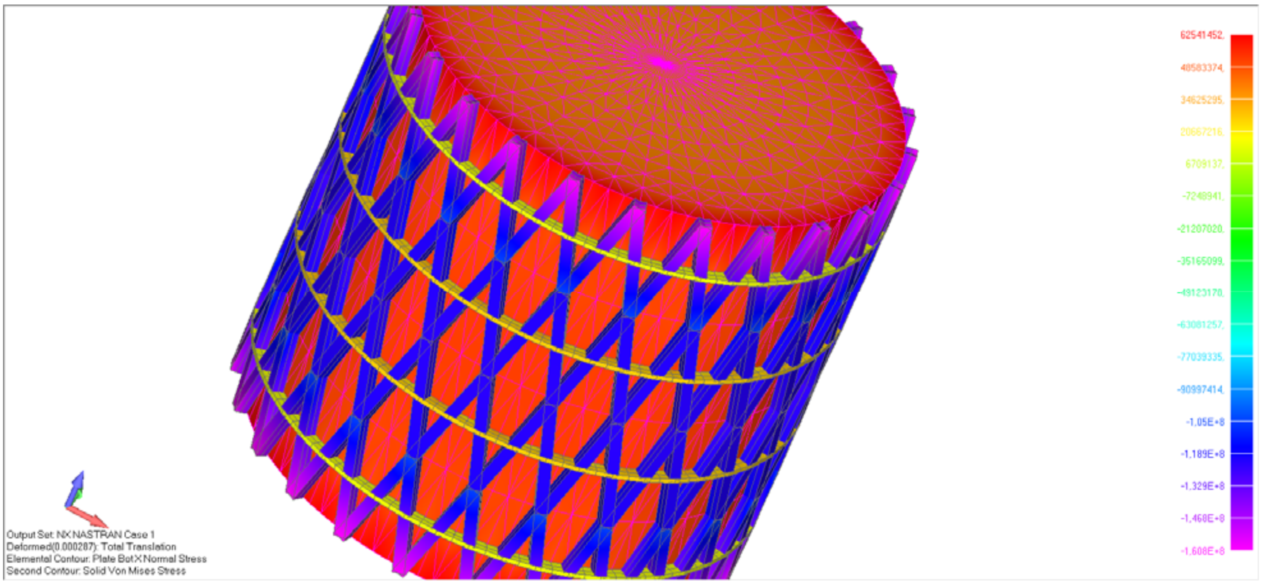

Figure 5. Numerical modeling of the behavior of the column C-3.

3. Discussion

To evaluate the potential efficiency of concrete composite columns reinforced with composite lattice structures, analysis of concrete columns with the foregoing overall dimensions and various types of reinforcements has been performed. The results of calculation are presented in Table 2 in which the upper four lines correspond to columns with typical steel reinforcement, whereas the last line demonstrates the characteristics of the column reinforced with carbon-epoxy lattice structure with the following parameters: angle of helical ribs 15º; the number of pairs of symmetric helical ribs 24; thickness of anisogrid structure 15.0 mm; width of helical rib cross section 15.0 mm; width of hoop rib cross section 10.0 mm.

Table 2. Characteristics of concrete columns with various reinforcements.

Reinforcing Element	Weight, kg	Volume Fraction of Reinforcement, %	Ultimate Predicted Axial Force, MN
Traditional steel reinforcement with minimum allowable fraction	255.9	0.01 – 0.25	1.46
Steel reinforcement with standard fraction	259.2	1 – 2	1.55
Traditional steel reinforcement with maximum allowable fraction	264	3	1.62
Reinforcement with steel frames	321.6	up to 15	2.9
Reinforcement with composite lattice structure	228.7	24	> 5.55

4. Conclusions

As follows from the foregoing discussion, composite lattice structures can be weight efficient elements to reinforce concrete columns. Application of lattice structures can result in weight reduction (due to low density of modern composites) and significant increase of the column load-carrying capacity. Additional benefit of composite reinforcement is high corrosion resistance and fatigue strength in comparison with steel.

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However, the proposed structures suffer from two main shortcomings. The first of them is associated with relatively low fire resistance of polymeric composites. This disadvantage can be partially overcome by the location of the lattice structure which is inside the concrete column and is protected against fire by the external concrete layer the thickness of which can be properly designed. The second shortcoming follows from relatively high cost of composite materials (which is typical for all columns reinforced with composites). In application to lattice composite reinforcing elements, significant cost reduction can be reached using low cost glass or basalt fibers in the ribs and low cost wet filament winding applied to fabricate lattice structures [8,9].

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