The Foundations with Composite Reinforcing Various Types Work Analysis

A Subbotin*, A Shagina, G Skibin, M Shutova,

Platov SRSPU(NPI), Prosvesheniya Str. 132, Novocherkassk, 346428, Russia

E-mail: Subbotin_ai@mail.ru,

Abstract. The article deals with the composite reinforcement use in the foundations’ construction under difficult geological conditions and aggressive groundwater. The pile foundation of a two-story cottage was calculated using two types of reinforcement in the pile cap: traditional metal reinforcement and composite fiberglass. The modern regulatory documents requirements governing the calculation of structures with composite reinforcement were taken into account. The use composite reinforcement has been revealed not to give a significant advantage in the pile foundations cost, it is effective when the structure is used in aggressive environments: the resistance of fiberglass reinforcement plays a crucial role in combination with special concretes.

Introduction

Composite reinforcement is not new, but still not enough studied and widespread building material.

The tensile strength of the PCR (polymer composite reinforcement) is 2.5 times higher than that of the metal. However, at high tensile strength, the PCR has a significantly lower, by 3.6 times, elasticity modulus than that of a metal, and, consequently, a low resistance to deformation [1, 2]. In addition, the lack of reinforcement made of fiberglass is a relatively low performance on fire resistance.

The PCR destruction occurs without a yield point and has the brittle destruction nature, while having a higher strength indicator, which leads to a sharp, sudden, without previously visible defects, the structures’ destruction [3].

To evaluate the GCR (glass composite reinforcement) work in concrete structures in bending, the tests of beams with a section of 80x160x1400 [4] have been carried out. Theoretically, the beams were calculated on the first limit state - the moment of cracking.

From the calculations it can be seen that the moment of the beam cracking with steel reinforcement is 1.2 times higher than the beam with the GCR. This is due to the lower modulus of elasticity in fiberglass reinforcement.

The moment of cracking, obtained during the experiment, in a beam reinforced with GCR, is lower than in a beam reinforced with steel reinforcement 3.7 times [5]. Cohen M., Montepone A., Potapenko S. conducted a numerical experiment with the finite element model calculation of a beam reinforced with automatic gearbox with modeling of reinforcement adhesion to concrete and the cracks appearance [6]. The team under supervision of E. O. Ibar carried out the calculation in the nonlinear stage of the beam reinforced material work by the PCR [7].

Considerable work on the study of the behavior of reinforced concrete loads under load, reinforced with composite reinforcement or a combined method was carried out at the Rostov University of Civil
Engineering in Rostov-on-Don. According to the approved research program [8], a number of experiments, the results of which are presented in scientific papers have been carried out [9].

The bearing capacity of beams with combined reinforcement depends on the steel reinforcement percentage. Beams with one or two composite rods showed ultimate strength, respectively, 13 and 22% lower. However, without taking into account the maximum permissible norms of beams deflections, the comparison of the ultimate strength values is not entirely correct, since the elastic modulus for fiberglass reinforcement is 3.64 times lower than that of steel [10].

**The pile foundation with composite reinforcing analytical calculation**

To study the operation of foundations with various types of reinforcement, the calculation of the pile foundation of a two-story residential building in Rostov-on-Don has been carried out.

On the plot there are four identical two-storey houses without a basement and one house with a mirrored layout with the basement presence (Figure 1).

A typical object is a two-story building with the dimensions in terms of 13.52x8.34. External walls consist of a Poromax ceramic block, 380mm thick, lined with facing brick. The inner walls are made of a Poromax ceramic block, 250 mm thick. The overlap between the first and second floor in the houses of precast concrete hollow core [11, 12].

![Figure 1. Engineering geological section](image)

When designing the house foundations the following features that affect the choice of the type of foundation were taken into account:

- high level of groundwater, their aggressiveness with respect to metal fittings (seasonal fluctuation of groundwater table, groundwater column at the time of engineering and geological surveys at the level of 2.8m);
- The possibility of landslide processes on the slopes;
- insufficient knowledge and anisotropy of the bulk layer properties, a significant thickness of the bulk layer, excluding its export and replacement.

The pile foundation from bored piles was adopted. The length of the piles is 5m and 7m, designed in such a way that, based on the engineering-geological section conditions, a penetration into the layer of limestone EGE-2 of at least 500 mm occurred to transfer the load to the rocky soil. This allows the pile to work as a pile rack to ensure the characteristics laid down in the project (Figure 2).
Figure 2. The piles arrangement plan

Figure 2. Layout of piles and section AA.

Pile cap thickness - 300m. Piles are bored with a diameter of 300mm. The basement construct is shown in Figure 3

| no | Designation          | Name          | amount | Mass, pcs., kg | Notes   |
|----|----------------------|---------------|--------|----------------|---------|
|    | Pile cap PM-1 parts  |               |        |                |         |
| 1  | GOST 57-81-82*       | Φ10 A400 l=450| 96     | 0.27           | 44 m.p  |
| 2  | GOST 57-81-82*       | Φ12 A400 l=307,2| -      | 0.88           |         |
| 3  | GOST 57-81-82*       | Φ10 A 400 l=250| 753    | 0.15           | 188 m.p |
| 6  | GOST 57-81-82*       | Φ10 A 400 l=550| 412    | 0.34           |         |
|    | materials            |               |        |                |         |
|    | B15 class concrete   | 8.82          | -      | M³             |         |
|    | C-1 pile parts       | 23            |        |                |         |
| 4  | GOST 57-81-82*       | Φ12 A400 l=4420| 4      | 3.88           | 18 m.p  |
| 5  | GOST 57-81-82*       | Φ8 A400 l=950 | 13     | 0.37           | 13 m.p  |
B15 class concrete

|        |        |        |
|--------|--------|--------|
|        | 0.3    | -      |
|        | M³     |        |

**Figure 3.** Reinforcement pattern and pile foundation specification

The pile foundation construction is carried out taking into account the required number of piles in the foundation composition and the design requirements for the minimum size of the pile cap in the plan and in height.

The bearing capacity of a pile with a diameter of 300mm is equal to:

\[ Q = \frac{1}{14} \times 5.9 \times 0.07 = 295kN, \]  

Thus, the maximum pitch is:

\[ \frac{295}{77.73} = 3.82 \text{ m}. \]

The calculation is made for the pile caps under the inner wall for two types of reinforcement: metal reinforcement (full load - load 1) and fiberglass (load 1 and load 2 (only permanent and long temporary loads). The results of the calculation of reinforcement analytically are summarized in Table 1.

**Table 1.** The result of the reinforcement selection

| Wall type   | Reinforcing arrangement | Metal reinforcing | Fiberglass reinforcing |
|-------------|-------------------------|-------------------|-----------------------|
| External wall | In the span            | 0.92              | 1.10                  |
|             | On a support           | 1.52              | 1.81                  |
|             | Crosscut               | not required      | not required          |
| Internal wall | In the span            | 1.24              | 1.34                  |
|             | On a bracket           | 1.58              | 1.70                  |
|             | Crosscut               | 0.05              | 0.06                  |

Thus, according to the calculation results (Tab. 1). The difference in the area of cross reinforcing of metal reinforcing and GCP makes 7 … 19% in favor of metal reinforcing.

It is structurally accepted reinforcing from three cores of Ø12 (As = 3.39 cm²) on the top belt and it is symmetric on the lower belt that satisfies according to requirements both for metal reinforcing and for glass-composite materials.

**Numerical calculation of the pile foundation with composite reinforcing**

Thus, according to the calculation results (Table 1), the difference in the area of transverse reinforcement of metal fittings and GCP is 7 … 19% in favor of metal fittings.

Structurally accepted reinforcement of three Ø12 rods (As = 3.39 cm²) along the upper belt and symmetrically along the lower belt, which satisfies the requirements for both metal reinforcement and glass composite.

To calculate the pile foundation, an end-element model was built and calculated in the ANSYS PC. PC ANSYS is widely used to calculate the stress-strain state of reinforced concrete beams with defects (cracks, chips) [13, 14]. Thus, the authors of NSACU (Sibstrin) conducted a series of studies of a single-span reinforced concrete beam with an artificial defect in the stretched zone under the action of static short-term loads [15, 16].

For an adequate design model, a foundation section, which included 5 piles was built. In the calculation of the estimated SSS of the foundation middle part (central pile). The design model consists of concrete bodies (pile cap and piles), reinforcement (longitudinal rods and clamps), a soil massif (Figure 4).
Figure 4. Finite-elemental model of the foundation: a) General view of the FEM-model, taking into account the soil base; b) FEM-model of pile cap with piles; c) FEM-model loading. The calculation results of the foundation building structures are shown in Fig. 5 for structures with metal reinforcement, in Fig.6. for the constructions with fiberglass reinforcement (calculation is made only for loading 2).

Figure 5. Calculation results for structures with metal reinforcement: a) calculation results of deflections, mm; b) stress calculation results, MPa

Figure 6. Calculation results for structures with fiberglass reinforcement: a) the deflections calculation results, mm; b) stress calculation results, MPa

The calculations were also made for the two types of reinforcement according to the following requirements: strength according to the section limiting moment, deformation in compressed concrete, deformation in the tensioned reinforcement, strength along the concrete strip between the inclined
sections, strength according to the inclined section, deflection, crack width, short-term and long-term. For a two-story house, all the indicated requirements for the calculations are satisfied. In the case of increasing loads (superstructure attic floor) reinforcement of fiberglass fiber does not pass on the requirements for the crack opening width, which exceeds 0.5 mm from the condition of protecting structures from aggressive environmental influences.

Thus, when designing pile foundations, it was established that the glass composite reinforcement use with respect to metal does not have any particular economic efficiency: at a cost of 1 m reinforcement of one diameter is 15% less, fiberglass reinforcement requires 7-19% more in cross section. In addition, due to the high GCP deformative properties, the deflections and the width of crack opening in structures exceed similar parameters for the structures with metal reinforcement. In cases where the structure is used in aggressive environments, the resistance of fiberglass reinforcement plays a crucial role in combination with special concretes.

References
[1] Rimshin V I, Merkulov S I 2016 On the rationing of the characteristics of core nonmetallic composite reinforcement (Industrial and Civil Engineering) 5 22-26.
[2] Zinnurov T A et al. 2019 Numerical modeling of composite reinforcement with concrete (Journal of Physics: Conference Series. IOP Publishing) 4 042046.
[3] Maximov S P, Bashkova Yu B, Vshivkov E P 2015 Pilot studies of work of fiberglass reinforcements when reinforcing concrete structures (Universum: technical science) 6.
[4] Round B B, Malykh V V 2013 Pilot studies of the bent concrete elements with the combined reinforcing by steel and fiberglass cores.
[5] Ding B 2017 Axial Compression Tests on Corroded Reinforced Concrete Columns Consolidated with Fibre Reinforced Polymers (Kemija u Industriji) 66.
[6] Cohen M, Monteleone A, Potapenko S 2018 Finite element analysis of intermediate crack debonding in fibre reinforced polymer strengthened reinforced concrete beams (Canadian Journal of Civil Engineering) 10 840-851.
[7] Ibars E O et al. 2018 Numerical analysis of reinforced concrete beams strengthened in shear by externally bonded (EB) fibre reinforced polymer (FRP) sheets (Hormigón y Acero) 285 113-120.
[8] Mervat X, etc. 2012 Durability and deformability of the bent elements from heavy concrete reinforced by fiberglass and steel reinforcing (New technologies) 4.
[9] Polish Items, Mailyân D R 2014 About specification of calculations of deflections of the beams strengthened by composite materials (the Scientific review) 12(2) 493-495.
[10] Mailyân D R 2013 Polish Items. Impact of steel and composite reinforcing on width of disclosure of normal cracks (Engineering bulletin of Don) 2.
[11] Shagina A I, Shutova M N 2018 Use of structural materials for reinforcing of the foundations working in hostile soil environment of the Mechanic of soil in geotechnics and foundation engineering, 296-300.
[12] Subbotin A I, Shutova M N, Shagina A I 2019 Estimating efficiency of composite reinforcement applications in foundations of low-rise buildings (Geotechnics Fundamentals and Applications in Construction: New Materials, Structures, Technologies and Calculations) 368-374.
[13] Hua Zhu 2016 Crack formation of steel reinforced concrete structure under stress in construction period (Frattura ed Integrità Strutturale) 36 191 – 200.
[14] Fisker J 2014 Shear capacity of reinforced concrete beams without shear reinforcement (PhD thesis. Aarhus (Denmark): Aarhus University)155.