Strength of the monolithic coverings with non-fixable formwork of steel fibro-tuffcrete elements

Yu M Khasauov*, M M Atabieva, A A Chochuev
Kabardino-Balkarian State University named after H.M. Berbekov, 173 Chernyshhevskiy, Nalchik, 360004, Russian Federation

E-mail: hassau@mail.ru

Abstract. The article presents the strength study results of the tuffcrete flexible monolithic structures with fixed formwork, combined reinforced rods and fibers. The nature and degree of the fibers percentage influence in the tuffcrete element of the fixed formwork, the dimensions of the fixed formwork elements’ fiber-reinforced section and the strength of monolithic tuffcrete on the normal strength to the longitudinal axis of the monolithic combined-reinforced bending floor structures, as well as on the adhesion strength of the fixed form contact line with concrete monolithic, are analyzed. The experimental dependences that make it possible to more economically design the structures under consideration, taking into account the strength and quantity parameters, as well as the geometric dimensions of their individual components, are proposed.

Introduction
The studies of some authors [1-3] in the field of steel fiber concrete showed that bent elements’ stretched zone fiber reinforcement significantly increases their strength, crack formation time and section stiffness. However, in many cases it is not possible to completely replace the bar reinforcement with steel fiber in view of the fact that the required strength at high loads is not provided. The fiber reinforcement’s use in combination with bar reinforcement, i.e. the so-called combined reinforcement is more appropriate in this case. [4].

The authors of [5-8] in their studies prove the presence of a positive effect of fiber reinforcing the lightweight concrete and the structures made of them.

In [9], a rational placement of the materials in precast-monolithic reinforced concrete structures constructed in stages is proposed.

The condition for the rational placement of the combined prefabricated (rods and fibers) elements in prefabricated monolithic structures is justified and proposed earlier in the author’s work [10,11]. The author considers it more acceptable to use the zonal placement of materials in prefabricated monolithic flexible structures, the prefabricated part of which is combined with the reinforced (bar and steel fiber reinforcement) part in the form of fixed formwork, and the monolithic part is made of ordinary heavy or light concrete.

The monolithic flexible structures with fixed formwork made of lightweight concrete, in particular, tuff concrete, have hardly been studied.

Therefore, conducting the studies of the stress-strain state of flexible monolithic structures with fixed formwork of various types of concrete reinforced with rods and steel fiber is an urgent problem.
The aim of the work is:
- to strength the study of bent concrete bendable monolithic structures with fixed formwork combined with reinforced rods and fibers;
- to identify the nature and degree of influence of the fibers’ percentage in the tuffcrete element of the fixed formwork, the fixed formwork elements fiber reinforced sections’ sizes and the strength of monolithic tuffcrete on the strength normal to the longitudinal axis of monolithic combined reinforced bending structures with fixed formwork and strength on the fixed formwork concrete monolithic contact line.

Obviously, the studied structures’ normal sections strength depends on: strength and deformation properties of “monolithic” and “precast” concrete, the ratio geometric sizes sections prefabricated element and prefabricated monolithic design, quantity and location of the bar and fiber reinforcement in the cross section.

Ratio $h_{dd}/h_{vs} = 0.86-0.9$ varied due to the “monolithic” concrete height with a constant height of the precast element in the precast monolithic structure.

In order to take into account the monolithic concrete properties influence on the studied dependent parameters, another variable factor is adopted - the “monolithic” concrete cube strength. The strength of the “monolithic” tuffcrete varied in the range 9.9-14.4 MPa. The coefficient of the precast monolithic sections’ rod reinforcement was constant for all the samples $\mu_s = 0.0039$. Considering that a part of the tensile forces is absorbed by fibers, the condition $\mu_R \geq \mu_s$ was met. At the same time, the volume percentage of reinforcing the prefabricated element with fiber changed to $\mu_v = 1-2\%$. Accordingly, the variation with the percentage of combined reinforcement $\mu_{fa} = 0.72-1.44\%$ was obtained.

The longitudinal working reinforcement of the prefabricated elements was steel rods of class A400 with a diameter of 8, 10 and 12 mm.

For the dispersed tuffcrete reinforcement, fibers of a periodic profile were used, $d_f = 1$ mm, $l_f = 100$ mm, with temporary tensile strength $R_f = 620$ MPa.

The prototypes were tested as single-span freely supported beams with a design span of 165 cm. The loading was carried out in the third span by two concentrated forces.

The experimental studies’ results of tuffcrete monolithic structures with the fixed formwork combined with reinforced rods and fibers are presented in Table 1, as well as in Figures 1 and 2.

When loading the combined - reinforced (BM - 1ij , BM – 2ij) and reference (BM-0ij) bending elements to the levels respectively 0.21 and 0.24 from the destructive moment $M_{dy}$, deformations of the compressed and stretched zones developed approximately identically (Fig. 1).

At loading levels of the combined reinforcement beams equal to $(0.21 \div 0.25) M_{dy}$ and reference samples - (0.24-0.29) $M_{dy}$, the deformations of the extreme stretched fiber, respectively, SFTC and the tuffcrete reach limit values $\varepsilon_{fb1,a} = (25 \div 45) \cdot 10^{-5}$ and $\varepsilon_{fb1,u} = (20 \div 35) \cdot 10^{-5}$, which may indicate cracking.

An analysis of the data in Table 3 shows that elements with combined reinforcement were destroyed at bending moments significantly exceeding the destructive moments of the elements with rod reinforcement. The increase in the strength of normal sections due to fiber reinforcement ($\mu_f = 2\%$) amounted to 21-37% (BM -2ij and BM - 0ij).

An analysis of the behavior of the samples under study along the contact line “fixed formwork - monolithic concrete” (Figure 2.) shows that the shear strain for all samples to a level equal to 0.5-0.6 $Q_s$ is approximately elastic.

**Table 1.** The bent elements normal sections’ strength with combined reinforced fixed formwork.

| Brand Series | Section height, [cm] | $A_v$, [cm$^2$] | $\mu_{fp}$ [%] | $M_{dy}$, [kN/m] |
|--------------|----------------------|----------------|---------------|------------------|
| BM - 222    | 27.2                 | 2.027          | 2             | 32.0             |
| BM - 022    | 27.5                 | 2.027          | 0             | 23.5             |
Then plastic deformations start being developed, as evidenced by the curves’ fracture in the graphs «Q - $\varepsilon_{sh}$», which is more pronounced in the samples without fiber reinforcement (BM-0ij). Fiber reinforcement of prefabricated elements ($\mu_{fa} = 2\%$) contributed to the increased effort Q, to which the shear strain is elastic, by 20-50%. The shear strain $\varepsilon_{sh}$ of the combined reinforced specimens make up 60-75% during elastic work, and 30-50% of the corresponding deformations of samples without fiber reinforcement under elastic-plastic work (Figure 2).

Based on the processing of the multifactor experiment data, experimental dependences are obtained for assessing the bearing capacity by the normal sections (1) and the shear deformations along the fixed formwork contact surface with monolithic concrete (2), taking into account the nature and influence degree of the studied factors on them.

The strength of the sections normal to the longitudinal axis of the element can be estimated by the formula:

$$M_u = b h_{os} A_s \left( 5229.2 \mu_{fa} + 3.82 R - 436 h_{os} / h_{os} + 568 \right)$$

(1)

**Fig. 1.** Deformations of the experimental bent elements with a height of: a - extreme compressed concrete fiber; b - stretched bar reinforcement
dependence (1) characterizes the linear relationship of thehear deformations at the contact ∙. According to the element over the area combined reinforcement is directly proportional to the reduced reinforcement coefficient of the precast element over the area µfa, the solid concrete strength R and inversely proportional - from the ratio hof / hoc.

Most significantly on the normal sections’ strength affects the coefficient µfa, and about 4 times less influence the strength of monolithic concrete and the ratio hof / hoc.

The nature and influence degree of fiber reinforcement µfr, the solid concrete strength R, and the height of the monolithic section h2 on the shear strain εsh can be expressed as a formula:

εsh= 50,74-191,25 µfr - 0,95 R -1,31 h2

(2)

The shear deformations at the contact “fixed formwork” – “monolithic concrete” are more dependent on the fiber reinforcement coefficient in the volume µfr.

The accuracy of the proposed experimental dependencies is estimated. According to Tables 2 and 3, they give good convergence with the experimental results.

**Table 3.** The experimental and calculated shear strain values’ comparison.

| Brand Series | ε\text{\text{exp}}_{sh,m} \cdot 10^5 | ε\text{\text{d}}_{sh} \cdot 10^5 | (ε\text{\text{exp}}_{sh,m} - ε\text{\text{d}}_{sh})/ ε\text{\text{exp}}_{sh,m}, [%] |
|--------------|---------------------------------|-----------------|--------------------------------------|
| BM-222       | 4                               | 3.4             | 15.0                                 |
| BM -022      | 5.8                             | 5.23            | 9.88                                 |
| BM -202      | 6                               | 5.68            | 5.38                                 |
| BM -002      | 8.6                             | 9.5             | -10.49                               |
| BM -220      | 10.2                            | 10.78           | -5.7                                 |
| BM -020      | 14.6                            | 14.61           | -0.04                                |
| BM -200      | 15.3                            | 15.06           | 1.59                                 |
| BM -000      | 21.8                            | 18.88           | 13.39                                |
|     |     |     |     |
|-----|-----|-----|-----|
| BM -211 | 7.8 | 8.86 | -14.0 |
| BM -011 | 11.8 | 12.68 | -7.46 |
| BM -121 | 9.15 | 8.4 | 8.2 |
| BM -101 | 11.2 | 12.67 | -13.1 |
| BM -112 | 6.3 | 5.7 | 9.52 |
| BM -110 | 14 | 15.03 | 7.36 |

**Figure 2.** The dependence of shear strains along the contact line “Fixed formwork” – “monolithic concrete” with the full beam height $H=27.3$ cm.

**Summary**

1. The combined reinforcement of the flexible monolithic tuffcrete structures’ fixed formwork elements helps to increase: the strength of their normal sections up to 37%; crack formation moment up to 16%; the shear deformations’ reduction along the contact line of the precast element with monolithic concrete up to 70%.

2. The use of the combined reinforced elements in flexible monolithic structures is more effective with a fiber orientation high degree in the direction of tensile forces, i.e. at low heights of the fixed formwork sections. Based on this, in order to increase the monolithic bending elements normal sections strength, it is necessary to increase the content of fibers in the section, limiting the fiber-reinforced layer height.

3. When arranging the sections of monolithic bending elements with steel-fiber-reinforced concrete fixed formwork and assigning the fiber reinforcement parameters, their strength can be estimated from the experimental dependencies.

**References**

[1] Vasiliev E B, Zakharov L V 1978 Beams with the dispersed-reinforced cement-polymer concrete layers *Concrete and reinforced concrete* 9 25-27.
[2] Jahlenius A 1982 Steel fibers as shear reinforcement in concrete beams Nordisk Betong 2 (4) 239-241.

[3] Getun G V, Lysenko E F, Khasauov Yu M 1986 The stress-strain state of bent reinforced concrete elements reinforced in the stretched zone with a layer of steel fiber concrete, Non-linear methods for calculating spatial concrete structures Proc. doc. All-Union scientific - tech. conf. - Belgorod.

[4] Eisenschmidt P O 1983 Deformability of flexible steel-fiber-reinforced concrete beams having fiber and combined reinforcement under long-term load action: author (Candidate of Technical Science, Riga).

[5] Khasauov Yu M, Lysenko E F, Zhangurazov A M 1994 Optimization of sections of precast monolithic flexible elements reinforced with rods and fibers Bulletin of KBSU. Series, Engineering, Nalchik 1 15-20.

[6] Hannant D I 1972 Steel fibers and lightweight becums Concrete 6 (8) 38-40.

[7] Khasauov Yu M, Dzhankulaev A Ya, Misirov M Kh, Zhilokov I B, Mazanov K A 2018 Efficiency of reinforcing tuffcrete with steel fiber Engineering Journal of the Don 2. ivdon.ru//ru/magazine/archive/n2y2018/4895.

[8] Chernousov N N 1987 Ribbed slabs of fine-grained slag and slag concrete with dispersed reinforcement with steel fibers of the supporting zones of the longitudinal ribs (abstract dis. ... cand. tech. sciences. Voronezh).

[9] Kirillov A P, Chernyak T V, Rubin O D 1986 Features of resistance of precast-monolithic reinforced concrete structures, erected in stages Energy construction 7 30-34.

[10] Khasauov Yu M 2018 Rational placement of a steel fiber in sections of the combined and monolithic bent reinforced concrete elements Materials Science Forum 931 358-361.

[11] Khasauov Yu M, Khasauov A M, Misirov M Kh, Khutuev O M, Pshukov K Kh 2020 Fracture resistance and deformability of steel-fiber-reinforced concrete precast-monolithic flexible elements Engineering Journal of the Don 2. ivdon.ru//ru/magazine/archive/n2y2020/6325.