Suspensibility of Steel Fibre Reinforced Concrete Values with External Ribbed Armature

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Abstract. In 2013, Lviv National Agrarian University patented reinforced concrete beams containing fibre external reinforcement and steel reinforcement tape with end anchors. Such technical solutions aimed at significantly reducing the cost of construction by reducing the complexity of manufacturing due to the complete replacement frames and ribbon fibre. The task of this work was to determine experimentally the bearing capacity of normal sections of steel-fibre reinforced beams with ribbon valves and compare them with the designed according to normative documents and to develop proposals for a refined calculation methodology. For studies of the bearing capacity of normal sections, 3 beams were manufactured in the size of 1500x150x60 mm. The first beam B-1, reinforced with steel strip valves in the sizes of 1500х60х3 mm with end stops, executed without fibres; The second and third beams (BF-2, BF-3) contained, in addition to the specified reinforcement, fibres in the amount of 1.59 kg and 2.12 kg, which corresponded to the coefficient of fibre reinforcement in volume, $\rho_{fv}=1.5\%$ і 2% respectively. For disperse reinforcement, an anchor fibre type with curved ends HE 1050 type in diameter of 1 mm and length of 50 mm was taken, because it is a mass produced fibre in Ukraine and abroad. The percentage of fibrous reinforcement in the volume of samples taken = 1.5% and 2%, to obtain a power effect, ensuring a sufficient bearing capacity for both normal and inclined cross-sections. As a binder for the production of concrete C20/25, cement of the mark 400 (activity 42.3 MPa). Experimental samples were made of fine-grained concrete, for the manufacture of which Yasinetskyi sand was used with a grain size unit of no more than 2.5. The composition of the mixture was chosen in such a way that the fibres could not settle down to the bottom of the forms; the cone's settling did not exceed 4-6 cm. Characteristic issue was that with an increase in the number of fibre reinforcement in the beams there was a large number of cracks. Closer to the supports, they were tilted to the longitudinal axis, indicating a joint effect on the cracking process, both bending moments and transverse forces. It has been experimentally established that the bearing capacity of steel-fibre reinforced composite reinforced beams was 16% and 21% higher than the percent reinforcement of fibres 1.5 and 2, respectively, in comparison with steel concrete. For identical values of bending moments of strain relief, the deformation of the extreme compressed fibres of concrete and the deflection of beams containing fibres are smaller than fibres without beams. The calculation of the deformation method gave a good convergence of theoretical and experimental results. Ukrainian norms for the design of steel-fibre-reinforced concrete structures require the replacement of a power calculation method using rectangular stresses of strain with a deformation method.
1. Introduction

There are known the designs of beams, in which the external reinforcement in the form of a steel strip acts as a longitudinal reinforcement, passed beyond the boundaries of concrete cross-section. The joint work of concrete and strips in such beams is provided with rigid end stops [1]. However, in such beams, for the perception of transverse forces and the strength of the sections inclined to the longitudinal axis, flat or spatial frames are required, which leads to additional labour costs. In 2013 The Lviv National Agrarian University patented a reinforced concrete beam, which includes reinforced fibres and external belt reinforcement with end anchors [2]. Such technical solution aimed at reducing the cost of the design by reducing the complexity of manufacturing in connection with the complete replacement of frame and ribbons by fibres.

According to the patent [1], the reinforced concrete beam with an outer longitudinal steel strip reinforcement with rigid end stops - contains fibre reinforcement. This solution allows during the preparation of a concrete mixture add it to fibre reinforcement, which will act as a transverse fitting. Fibre reinforcement in the front of normal cracks will also perceive a part of the tensile forces that can reduce the area of the cross-section of the bar reinforcement.

So far, there is no single approach to the calculation of the bearing capacity of steel-fibrous concrete bending elements due to the specifics of the operation of different types of fibres in the fronts of the crack and, accordingly, due to the difficulties in describing the deformation diagram of steel-reinforced concrete for tension [3-6].

The purpose of this work is to determine experimentally the bearing capacity of normal sections of steel-fibre reinforced beams with ribbon reinforcement and compare it with the designed one according to normative documents, as to develop proposals for a refined method of calculation.

2. Materials, designs of prototype samples, test program

The strength of fine-grained concrete of experimental steel-fibre-concrete samples is designed to correspond with the class of concrete C20/25, since many designs are made from this class.

For disperse reinforcement, an anchor fibre type with curved ends НЕ 1050 type in diameter of 1 mm and length of 50 mm is used, as it is a mass produced fibre in Ukraine and abroad. The percentage of fibrous reinforcement in the sample volume is adopted as $\rho_{fv}=1.5\%$ and 2% to obtain a force effect, providing a sufficient bearing capacity for both normal and inclined cross-sections. The percentages of reinforcing samples were taken from the condition that, when the fibre content is less than 0.7%, it is known that the strength of reinforcement in terms of strength and crack resistance is small, and when the content is more than 2%, the design is considered non-competitive.

As a binder for the production of concrete C20/25, cement of the mark 400 (activity 42.3 MPa) of the Ivano-Frankivsk plant was used. Experimental samples were made of fine-grained concrete, for the manufacture of which Yasinetskyi sand was used with a grain size unit of no more than 2.5. The mixture was made in a concrete mixer of coercive action. The composition of the mixture was chosen so that the fibres could not settle down to the bottom of the forms; the cone's settling did not exceed 4-6 cm. Based on these conditions, the following composition of the mixture was adopted: the cement of the Ivano-Frankivsk plant with activity 42.3 MPa - 549 kg, sand - 1647 kg, water – 285.5 litres.

The deformation and strength properties of fine-grained concrete and steel-fibre concrete were investigated on compressed prisms in the sizes of 400x100x100 mm and concrete cubes in the sizes 100x100x100 mm which were made simultaneously with beams.

The tape fittings are selected from steel St3ps5 (C245), which, according to the certificate, has a yield strength of at least 245 MPa, a strength of 372 MPa, a modulus of elasticity of $2 \times 10^5$ MPa, a relative elongation at break of 26%.

For studies of the bearing capacity of normal sections, 3 beams were manufactured in the size of 1500x150x60 mm. The first beam B-1, reinforced with band-shaped fittings in the sizes of 1500 x 60 x 3 mm with end stops, executed without fibres; The second and third beams (BF-2, BF-3) contained, in addition to the specified reinforcement, fibres of 1.59 kg and 2.12 kg, corresponding $\rho_{fv}=1.5\%$ і 2%.
The geometric dimensions of the end stoppers are designed taking into account that the height of the end support plate should be greater than the height of the compressed zone of concrete when the beam is broken, and the length of the welds should be such that their tensile strength be greater than the strength of the steel strip for tension.

For disperse reinforcement, anchor type fibres with curved ends of 1050 HE type produced by Ukrainian manufacturer "Silur" with a diameter of 1 mm and a length of 50 mm (Figure 1) were used.

![Figure 1. Geometric dimensions of an anchor fibre HE 1050 type](image)

The dimensions of the prototype samples were chosen to provide the conditions for the convenient arrangement of the measuring instruments and to obtain the orientation of the fibres, close to that of the actual building structures (Figure 2). The dimensions of the cross sections of the experimental samples of beams differed from the design within -0.5 ... + 1.08 mm.

![Figure 2. Geometric dimensions of experimental beams](image)

The experimental models were made in wooden forms, which were cleaned before the mixing. When the mixture is made in order to avoid the formation of "hedgehogs" from fibres, it is added to the concrete mixer gradually in small portions. After laying the mixture in forms on a vibration table, sealing was performed. Samples for 7 days were left in the forms under a layer of moistened sawdust, after which the shapes were disassembled, and the received prisms, cubes and beams were kept for 21 days under natural conditions.

This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

3. Strength and deformation properties of experimental beams materials
The results of tests of cubes and prisms on the press P-50 are given in Table 1. According to the results of tests conducted on the trash machine MUP-20 of stretched samples 700 x 100 x 60 mm with the composition of the concrete given above, the average strength of the steel-reinforced concrete on the tensile was equal to 2.49 MPa for $\rho_{fv}=0.015$ and 3.33 MPa for $\rho_{fv}=0.02$ [3]. The tape fixture of steel C245, based on the results of testing the samples with a 40x3 mm cut-off on the discontinuity machine MUP-20, has a yield point of $\sigma_y = 245.32$ MPa, $\sigma_u = 372.53$ MPa strength limit and modulus of elasticity $E_s=2.04 \cdot 10^5$ MPa.
Table 1. Mechanical characteristics of concrete and steel fibre concrete of experimental models

| Brand of the prism | Percentage of fibre reinforcement by volume ρfv, % | Average cubic strength of concrete fcm,cube, MPa | Strength of the prism fcm,prism, MPa | Average prism strength fcm,prism, MPa | Modulus of elasticity Ec⋅10^{-3}, MPa | The average value of the elastic modulus Ecm⋅10^{-3}, MPa |
|-------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| P-1.1             | 0                     | 29.06                | 24.34                | 23.25                | 26.86                | 27.11                |
| P-1.2             |                       |                      | 22.16                | 23.51                | 27.37                |                      |
| PF-2.1            | 1.5                   | 29.06                | 28.55                | 29.01                | 31.25                | 30.19                |
| PF-2.2            |                       |                      | 29.47                | 29.13                | 31.88                |                      |
| PF-3.1            | 2                     | 29.63                | 29.63                | 29.34                | 31.88                | 32.21                |
| PF-3.2            |                       |                      | 29.05                | 29.13                | 32.54                |                      |

The geometric dimensions of the end stoppers are designed taking into account that the height of the end support plate should be greater than the height of the compressed zone of concrete when the beam is broken, and the length of the welds should be such that their tensile strength be greater than the strength of the steel strip for tension.

4. Results of experimental studies of beams bearing capacity

Loading of the beams using a hydraulic jack was performed by one concentrated force applied in the middle of the run (Figure 3). The loading was carried out in steps in increments of approximately 10% of the predicted damaging load. When the loading value was applied to the expected destructive (80-90%) step, the application rate was reduced to 2-3%. The same was the case when the cracks formed.

![Figure 3](image)

Figure 3. Scheme of beams testing: 1, 2 - microindicators for measurement of bearing of supports; 3 - microindicator for measurement of deflections; 4 - microindicator for measuring deformations at the level of the outer compressed fibres; 5 - microindicator for measuring deformations at the level of the outer compressed fibres.
Between the steps of loading, the shutters for 10-15 minutes were made, during which the data from devices were taken. When cracks appeared, the value of the load at which it appeared was fixed; at each stage measurements concerning the width of its opening with the help of the BMB-2 microscope were also performed with marking of the peak (Figure 4).

In each of the three beams, the first crack formed under the line of force. In the beam B-1, the first visible cracks appeared at a load of 2.5 kN, in the beam BF-2 at a load of 2.6 kN, and in the beam BF-3 at a load of 2.8 kN. With further increase in load, new cracks were gradually formed (Figure 5).

It should be noted that in the beam B-1, besides the first one, four more cracks (two from the middle of the beam) were formed, which had a load of 16 kN (M = 560 kN·cm), a height of 5 ... 6 cm. They had a small angle of inclination to the longitudinal axis, which can be explained by the joint action of both transverse forces and bending moments.

In the beam BF-2 there were additionally eight cracks that grew in height and width up to loads of 16 ... 20 kN (560 ... 700 kN · cm). In the beam BF-3 formed, in addition, the first, another thirteen cracks, which also grew up in height dot loads 16 ... 20 kN.

The maximum width of the crack opening at a load of 16 kN (approximately 80% of the damaging load) in the beam BF-2 was equal to 0.34 mm, and beams BF-3 – 0.2 ... 22 mm. In the beam B-1 for a load of 14 kN (approximately 80% of the destructive load), the maximum width of the opening of the crack was equal to 0.4 mm.
As the loading increased, there was an increase in the deformations of both the tape reinforcement and the extreme compressed fibres of concrete. For identical values of the bending moments of the deformation of the reinforcement and concrete fibrobeton beams were smaller than the beams B-1. Increasing the content of fibres also contributed to the reduction of deformation. For example, at a bending moment of 420 kN \cdot cm, the relative deformations of the concrete of the outer compressed fibres of concrete $\varepsilon_c$ beams B-1, BF-2 and BF-3 were equal to 0.0011; 0.009 and 0.006, respectively, and deformations of the band reinforcement 0.00085; 0.0007 and 0.0005 respectively.

The deflections of steel-fibre reinforced beams were also smaller than steel-concrete at equal moments. For example, at a time of 420 kN \cdot cm, the deflections of the beams B-1, BF-2 and BF-3 were 0.38; 0.213 and 0.14 cm respectively.

It was experimentally determined that the bearing capacity of steel-fibre reinforced composite reinforced beams was 16% and 21% higher than the percent reinforcement of fibres 1.5 and 2, respectively, in comparison with steel concrete (Table 2).

| Code of the sample | $M_u^{[7]}$, $M_u^{[8]}$, kN-cm | $M_u^{\text{def}}$, kN-cm | $M_{\text{exp}}$, kN-cm | $M_{\text{exp}} / M_u^{[7]}$, | $M_{\text{exp}} / M_u^{[8]}$ |
|-------------------|-------------------------------|--------------------------|--------------------------|----------------------------|----------------------------|
| B-1               | 591.79                        | 594.88                   | 608.25                   | 1.03                       | 1.02                       |
| BF-2              | 755.31                        | 674.68                   | 705.55                   | 0.93                       | 1.05                       |
| BF-3              | 771.32                        | 699.59                   | 735.11                   | 0.95                       | 1.05                       |

$M_u^{[7]}$, $M_u^{[8]}$ - bearing capacity, calculated according to the design standards [7], [8];
$M_u^{\text{def}}$ - bearing capacity, calculated by the deformation method [3];
$M_{\text{exp}}$ - experimentally obtained bearing capacity

5. Results and discussions
The bearing capacity of the steel concrete beam B-1 was calculated by the simplified and deformation nonlinear method Eurocode 2 [7]. From Table 2 it can be seen that, as a simplified technique (with a rectangular calculation diagram of a compressed concrete zone), and deformation techniques using a complete diagram of deforming concrete under compression and Prandtl diagrams for steel stretching, allow us to determine precisely destructive bending moments. In calculations experimental data obtained for concrete ($f_c=23.25$ MPa, $E_c=27.11 \cdot 10^3$ MPa) and steel tape ($f_s=245.32$ MPa, $E_s=2.04 \cdot 10^5$ MPa).

The beams BF-2 and BF-3 were calculated according to the Ukrainian standard [8], according to which the calculation diagram was taken as a rectangular in a compressed and stretched band with ordinates $f_{c}$ and $f_{fct}$. The bearing capacity of the beam BF-2 was 7% lower than the experimentally obtained, and the beams BF-3 by 5% (Table 2). Percentage of fibre reinforcement 1.5% - $f_{c}=29.01$ MPa was accepted, and for percentage reinforcement 2% $f_{c}=29.34$ MPa (Table 1). Strength of tensile steel fibre concrete for percentage fibre reinforcement 1.5% $f_{fct}=2.49$ MPa, and 2% $f_{fct}=3.33$ MPa [3].

For the specified strength characteristics of steel fibre concrete, deformation diagrams of steel fibre concrete for expansion and compression, their analytical description and integral equilibrium equations, which are presented in the extended form in work [3], the calculation of these beams by the deformation method were performed.

The bearing capacity of the beam BF-2 is 16% higher than B-1, and BF-3 with -21%. Thus, the calculation of the deformation method gave a good convergence of theoretical and experimental results. Theoretical values of bearing capacity are 5% less than experimental (Table 2).

6. Conclusions
The results of the first experimental and theoretical studies of beams containing fibrous and external ribbon valves with end stops which were patented in Ukraine by the Lviv National Agrarian University in 2013 are presented in the article. The bearing capacity of the beam BF-2 $\rho_f=1.5\%$ is 16% higher,
than B-1, and BF-3 $\rho_v=2.0\%$ with $-21\%$ greater than B-1 (beam without fibres). For identical values of bending moments of strain relief, the deformation of the extreme compressed fibres of concrete and the deflection of beams containing fibres are smaller than fibres without beams.

The calculation of the deformation method gave a good convergence of theoretical and experimental results. The theoretical values of the bearing capacity are $5\%$ lower than the experimental one. Ukrainian norms for the design of steel fibre concrete structures [8] require clarification on the replacement of the power calculation method with the use of rectangular stresses of strain by the deformation method.

Since the use of fibres in steel concrete beams is intended to completely replace the lateral and partial replacement of longitudinal reinforcement, the studies of the bearing capacity of the cross sections, inclined to the longitudinal axis of such elements are required. Separate studies related to the calculation and design of end stops in order to reduce their material capacity while ensuring reliability should also be conducted.

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