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# Investigation on Concrete Beams Reinforced with Basalt Rebars as an Effective Alternative of Conventional R/C Structures

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**Abstract**

Basalt bars for concrete reinforcement called Basalt Fiber Reinforced Plastic (BFRP) is a new material, so it is necessary to identify the differences and limitations of their use in the concrete structures in relation to traditional steel reinforcement of concrete structures. The paper presents some chosen results of pilot research on the series of simply supported beams under flexure, reinforced with BFRP bars, compared to the reference beams with steel reinforcement. The tested beams were made of C30/37 concrete and reinforced with basalt bars with 8 mm diameter having and tensile strength evaluated from the tensile tests. The analysis of the beam deflection and cracking behavior has been presented. The results show the different character of the load-deflection relationship of basalt reinforced beams compared to traditionally steel reinforced beams, as well as the significant influence of the type and quality of anchoring on the process of basalt bars tensile process.


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*Keywords*: basalt rebars; BFRP; flexural capacity; reinforced concrete; bond.

## 1. Introduction

In the second half of the twentieth century occurred the evolution of composite materials on the basis of FRP (fiber reinforced polymer). Initially these materials were used in the military and aerospace industries. Gradually, over the last 30 years, FRP materials are being used in building construction. Composite materials based on FRP significantly increase the economic viability of construction of buildings and bridges [1-2].

Wherever a decisive role in the construction of civil engineering plays a strength, stiffness and resistance to environmental factors, composite materials based on FRP become outstanding replacement for conventional steel reinforcement.

Basalt bars of BFRP group (basalt fiber reinforced polymer) have a number of advantages comparing to steel reinforcement and other FRP composites, such as glass GFRP (glass fiber reinforced polymer) or carbon CFRP (carbon fiber reinforced polymer).

The chemical composition of basalts, which are made BFRP basalt fiber is somewhat different. In addition to the chemical composition, mechanical properties of basalt fibers originating from different sources are varied [3-5], probably due to the different chemical components and processing conditions such as the temperature of the fiber production. Basalt

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fiber tensile strength tends to increase from 1.5 to 2.9 GPa as the production temperature increases within the range of 1200 ~ 1375°C. This is due to the increase in the proportion of crystal nuclei basalt at lower temperatures. [3]. Basalt fiber Young's modulus ranging between 78 and 90 GPa, depending on the source, the highest values of BRFP modulus 90 GPA was reported in Russia [3]. Most reports indicate, that comparing to glass, the basalt fiber has higher or comparable modulus and strength [6], [4] and there have been reported some cases of significantly lower strength of basalt fiber than it was declared [5].

In addition to good mechanical properties, basalt has a high chemical and thermal stability, good thermal, insulating, electrical and sound properties, [4], [7]. Basalt thermal insulation is three times greater than the asbestos' one [7-8]. Due to good insulating properties, basalt is successfully used for fire protection [7-8]. Furthermore, basalt fibers have 10 times better electrical characteristics - insulating than glass fibers [7-8]. Basalt fibers are also significantly better chemically resistant than glass fibers, particularly in a strongly alkaline environment (e.g., with pipes made of basalt composite corrosive liquids and gases can be transported [9-10].

Basalt FRP bars are an excellent alternative as the reinforcement of bridge girders due to minimizing the weight of the slab having excellent resistance to corrosion effects, reducing repairs and a significant increase in usability [11].

Service life of concrete slabs with steel reinforcement for use in bridges, expected to be 25 years. However, the service life of panels with FRP reinforcement is usually expected to be at least 75 years (i.e. the period of use of the bridge)[12-13].

Nevertheless, BFRP reinforcing bars are a quite new material which mechanical properties are not yet completely defined. Due to the anisotropic structure of composite materials and isotopic steel reinforcement, the modified stress-strain relationships have to be considered.

Research described in this paper is aimed at experimental analysis of the limit states of strains and stresses in concrete beams reinforced with flexural basalt fiber composite bars (BFRP) to determine the strength parameters and acceptable cracking and deflections of such elements.

The aim of this study was to clarify the effect of basalt flexural reinforcement on ductility, deformability, ultimate stresses and damage mechanisms of structures reinforced with BFRP compared to traditional structures, reinforced with steel bars. Particular attention was paid to studies examining the impact of slip phenomenon, which may occur at the interface between the BFRP bars and the surrounding concrete.

Research carried out at the Faculty of Civil Engineering at Warsaw University of Technology started on models in the future will be continued on the natural elements.

## 2. Study of tensile strength of basalt bars

The purpose of the preliminary examination was to determine the tensile strength BFRP bars 8 mm in diameter and comparing the strength of the reinforcing steel bars. A special mounting system of the basalt bar ends has been used, to avoid a premature destruction of the material in the anchorage zone, on the other hand, the true tensile strength could be easily determined, without impairment of real bar properties.

Due to the fact that the BFRP bars are anisotropic material, basalt fiber strength in the transverse direction is very small compared to the very high strength in the longitudinal direction. This property requires the use of appropriate attachment at both ends of the test bar to be tested in a tensile testing machine. For this purpose, two steel pipe outer diameter of 40 mm with a wall thickness of 5 mm and a length of 400 mm each have been designed. At the end of the steel tube have been attached steel caps with a hole in the middle tor the tested BFRP bar. Mounting bar in a steel pipe BFRP has been done by filling the free space between the pipe and the rod with epoxy resin and hardener (the pipe anchors filling material to be determined on the basis of previous research trial). Anchor pipe length has been determined on the basis of previous test studies.

In Fig.1 the stress – strain relationship for basalt (BFRP) bars, obtained on the basis of own tensile tests in the testing machine is presented. These bars were used for construction of model RC beams described in this paper.

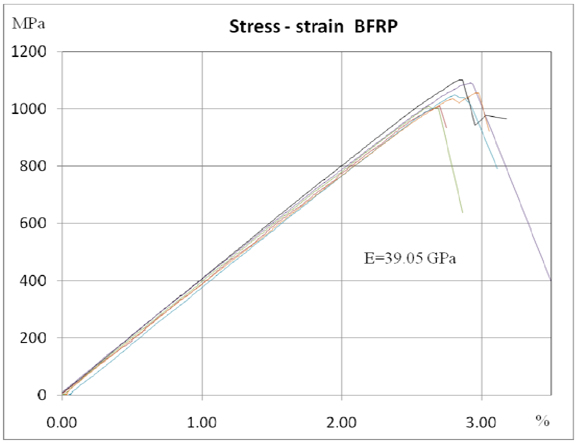


Fig. 1. The stress-strain relationship of basalt bars with a diameter of 8 mm, obtained from the tensile test

Figure 2 shows a basalt bar after the tensile test (it can be seen the characteristic basalt fiber splitting).

Fig. 2. Basalt bar (8 mm in diameter) after rupture in tension test [14]

Tab. 1 shows the rupture stresses in basalt rebars, the corresponding limit strains and the calculated modulus of elasticity of BFRP.

Table 1. Rupture stresses, limit of strains and longitudinal modulus of elasticity of 8 mm diameter BFRP bars

| Rebar | Rupture stress, MPa | Rupture strain, % | Elastic modulus, GPa |
|---|---|---|---|
| 1 | 1100.74 | 2.86 | 40.72 |
| 2 | 1009.16 | 2.71 | 38.73 |
| 3 | 1009.13 | 2.63 | 39.22 |
| 4 | 1089.43 | 2.92 | 39.63 |
| 5 | 1048.11 | 2.81 | 38.18 |
| 6 | 1054.17 | 2.95 | 38.34 |
| Average | 1051.79 | 2.81 | 39.05 |

It should be noted that the average strength of the BFRP ∅ 8 bars is more than double larger, and the limit strain at break and the modulus of elasticity are on average 5 times smaller than for steel St3S bars ∅ 8 ($f_y$ = 348 MPa from tensile test done in testing machine).

Modulus of elasticity of BFRP bars was determined from the stress-strain relationship, assuming complete linearity in the range of 20% to 50% of the tensile strength. The way in which the basalt bars were damaged in the tensile test was different from the breaking of conventional steel bars - the fibers have been destroyed by splitting. They separated into individual fibers and formed a splinters split during the disruption.

BFRP bars, despite its one-way micro - mechanical properties, are characterized by a very high tensile strength. Another very important aspect of the BFRP bars is that the stress - strain relationship is always linear, until destruction (see Fig.1). The linearity of this constitutive relationship is the major disadvantage associated with the use of BFRP bars in the concrete structures. Linearity means that there is no redistribution of stress and consequently the bars cannot be used in structures requiring large plastic deformations.

## 3. Research on load capacity and deformability of basalt reinforcement beams

The research program contained a bending test of three model beams with bottom reinforcement made of BFRP bars (diameter of 8 mm) and, for comparison, a bending test of three simply supported reference beams with a traditional bottom reinforcement made of in the form of a traditional bottom three steel bars with a diameter of 8 mm (St3S, $f_{yk}$ = 348MPa). All the tested beams have the following dimensions: $b$ x $h$ x $L$ = 80 x 140 x 1200 mm. During the tests, the beams were simply supported on two supports with a span of 1000 mm. Near the supports in all the beams steel stirrups for shear having a diameter of 8 mm have been provided.

The middle part of beams did not include any upper reinforcement and stirrups. Top reinforcement in the regions of supports of all tested beams consisted of two steel bars with a diameter of 8 mm. In all the beams the central bottom bar was protruded on both sides (as presented in the Fig.3) to enable the measurement of the slip during the loading process. The bottom reinforcement was located at a distance of 20 mm from the lower edge of it's section. On the side surface of the beam, there were arranged 7 pairs of bench-marks, every 20 mm from the bottom edge of the section. Strain measurement was made with an extensometer with a measuring base of 100 mm.

The actual average strength of concrete was tested on cubic samples - $f_{ck,\ cube}$ = 41.02 MPa, after conversion into cylindrical samples $f_{ck,\ cyl}$ = 0.8 x 41.02 = 32.82 MPa..

Figure 3 shows a BFRP bars of reinforced concrete beam. A reference steel bars of reinforced beam looked in the same way.

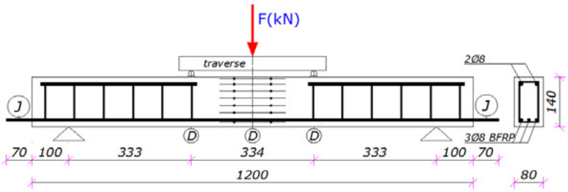


Fig. 3. Concrete beam with bottom reinforcement (BFRP bars) with visible distribution of bench-marks used to measure the strain with an extensometer; $J$ – slip measurement sensor; $D$ – deflection measurement sensor, dimensions in mm

Figure 4 shows the beam with BFRP reinforcement bars at the final load phase. The picture shows the mode of destruction as a result of transforming a beam into a tie system.


Fig. 4. The beam with flexural BFRP reinforcement with load capacity 45 kN [14]

Table 2 presents the results of experimentally obtained carrying capacities of the tested BFRP beams reinforced with 8 mm basalt bars (the maximum loading force $F_u$ and moment $M_{R,\,fl}$ carried by the beam critical sections and their mean values $F_{u,ave}$, $M_{R,fl,ave.}$ respectively) compared to the reference beams SRC with flexural steel reinforcement of the same diameter.

Table 2. Beam flexural capacity of basalt reinforcement bars (BFRP) and steel (SRC)

| | Steel reinforced beam | | Basalt reinforced beam | | | |
|---|---|---|---|---|---|---|
| | SRC1 | SRC2 | SRC3 | BFRP1 | BFRP2 | BFRP3 |
| $F_u$ ,kN | 37.5 | 35.0 | 40.5 | 47.5 | 47.5 | 45.0 |
| $F_{u,ave}$ ,kN | 37.6 | | 46,7 | | | |
| $\varepsilon_1$ , ‰ | -1.58 | -2.17 | -2.02 | -1.78 | -2.60 | -3.25 |
| $\varepsilon_7$ , ‰ | 4.18 | 5.69 | 6.52 | 9.43 | 13.60 | 7.76 |
| $M_{R,fl}$, kNm | 6.3 | 5.8 | 6.8 | 7.9 | 7.9 | 7 .5 |
| $M_{R,fl\ ave}$ kNm | 6.3 | | 7.8 | | | |

In the Table there are also included values of concrete strains $\varepsilon_7$ and $\varepsilon_1$, respectively at a distance of 20 mm (at the level of the reinforcement) and 135 mm from the bottom edge of the beam (at the top-level of compression zone).

For the reference beams with steel reinforcement the final reading of load was by 35 kN, for beams with basalt reinforcement, the final readings were for BFRP1, BFRP2 and BFRP3 beams at a load of: 35 kN, 45 kN and 40 kN, respectively

Figure 5 shows the experimental relationship between the load level and concrete strains $\varepsilon_7$, ‰ (at the level 7) for the two types of tested beams. Figure 6 shows the similar relationships between load and strains in the basalt reinforcement as well as strains in the steel reinforcement.

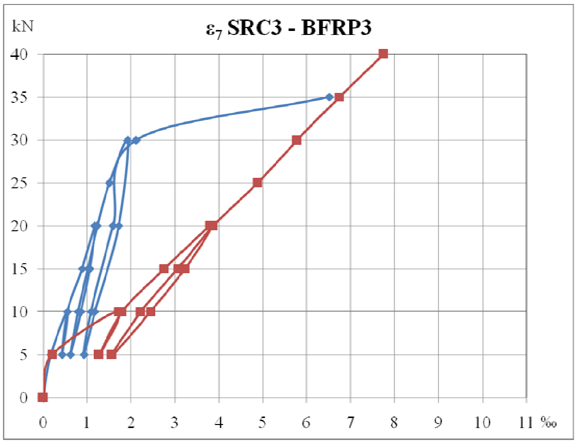


Fig. 5. Relationship between the load and concrete strains at the level 7 of the BFRP3 beam with basalt reinforcement (squares), and concrete strains for reference beam with steel reinforcement bars SRC3 (diamonds)

The tested beams were initially loaded and reloaded [kN], as shown in the table 3:

Table 3. Description of initial loading and reloading phases during the tests, values in kN

| No of cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Starting load | 0 | 10 | 5 | 20 | 5 | 30 | 5 |
| Final load | 10 | 5 | 20 | 5 | 30 | 5 | Till failure |

In the case of beams with basalt reinforcement the load - strain relationship is almost linear, and for beams with steel reinforcement yielding of reinforcement can be seen in the boundary phase of loading.

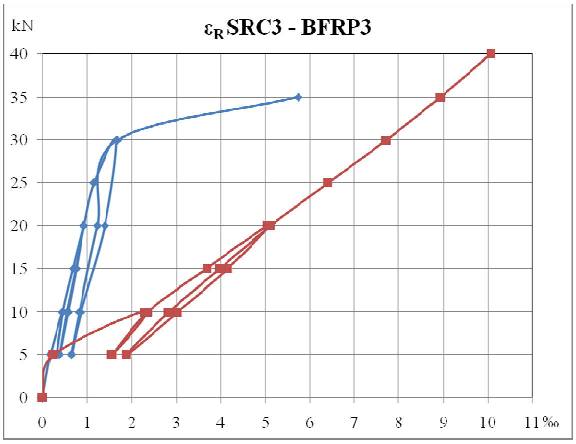


Fig. 6. Load – strain in reinforcement relationship for the beam with basalt reinforcement BFRP3 (squares), and the steel reinforcement bars SRC3 (diamonds)

The average value of destructive force for beams with basalt reinforcement was equal to 46.7kN compared to 37.6 kN for beams with steel reinforcement and was on average 24% higher. An average load (destructive bending moment) for beams with basalt reinforcement was equal to 7.8 kNm compared to 6.3 kNm for beams with steel reinforcement and was on average 24% higher.

Due to the much greater tensile strength of basalt bars comparing to steel bars, a mechanical equivalent degree of reinforcement by the following formulas has been specified:

$$\rho_{me,s} = \frac{A_s}{b \cdot d} \cdot \frac{f_{yk}}{f_{ck}} = \frac{3 \cdot 0.503}{8 \cdot 12} \cdot \frac{348}{32.82} = 0.167 , \tag{1}$$

$$\rho_{me,f} = \frac{A_f}{b \cdot d} \cdot \frac{f_f}{f_{ck}} = \frac{3 \cdot 0.503}{8 \cdot 12} \cdot \frac{1051.79}{32.82} = 0.504 , \tag{2}$$

Almost three times the difference of mechanical degrees of BFRP and SRC beams reinforcement indicates, that in terms of reinforced concrete theory, beams load-bearing capacity should be in the same proportion. Research showed different ways of destruction in both types of beams. In the steel reinforcement bars case, the cause of the destruction was the concrete crash in the compression zone.

However, in basalt reinforced beams, flexural capacity was only of 7.8 kNm, while the theoretical flexural capacity is of 14.25 kNm.

The destruction took place in the beams supporting zone, through shear, which explains the above given discrepancy between the actual and theoretical loading capacity.

In the tests there was no rupture of basalt bars in the flexural-reinforcement. The basaltic beam destruction was effected by the destruction of the concrete due to the higher degree of reinforcement equivalent. The destruction of the beam was due to shear force in the support zones and it had a brittle nature. However, it was not a rapid destruction, due to the continuity of the basalt reinforcement.

In the three tested beams, with ribbed basalt bars, there was not observed reinforcement slip. In the three reference beams reinforced with steel rods (plain bars) there was observed a slip in the final phase of the load (at the left and right end for the load 35 kN equal to: 4.65 mm and -5.93 mm for the beam SRC1, 0 and -2.24 mm for the beam SRC2 and - 0,56 mm and - 0.34 mm for the beam SRC3, respectively (reported - last readings).

Bond of FRP reinforcement to concrete depends mainly on the geometry and surface properties of the reinforcement bars [15], [16]. Compared to conventional steel bars in basalt bars:

- bars elasticity modulus in transverse direction is generally lower than that of steel,
- bars shear stiffness is much lower than that of steel.

In general, the bond strength of the BFRP reinforcement into concrete is similar to, or greater than the one for steel reinforcement bars [15].

It is essential that a good bond between the fibers and the polymer matrix FRP is maintained throughout the life of the structure [11].

Proper assessment of serviceability conditions and parameters affecting the behavior after cracking is very important in designing of reinforced concrete structures [17-18]. Due to the lower modulus of elasticity of basalt bars, SLS is often the deciding factor in designing of concrete sections reinforced with basaltic bars.

For beams reinforced with steel bars, SLS is usually determined for about 60 to 65% of nominal moment capacity. Several studies on SLS for structural members reinforced with FRP, show a lower value of design load in relation to the load limit at which the conditions of SLS are no more fulfilled. [19]. Design load for FRP reinforced concrete elements is about 35% of the limit load [20], Bishop, however, suggested to reduce the useful load to 25% of the nominal load capacity moment for overreinforced beams [21].

Reducing of tensile stress in the FRP reinforcement is used to prevent sudden break with the long-term loaded bars (known as creep rupture). Creep rupture strongly depends on the properties of FRP bars, environmental conditions and load time. In steel reinforcement such phenomenon does not occur [22-24].

In beams with basalt reinforcement rods, in contrast to the reference beam, the increase of deflection in relation to the load increase is practically constant, until the failure of the element; thus the deformations of the basalt reinforcement bars are linear.

Figure 7 and 8 show the variation of the deflection as a function of beam loading force.

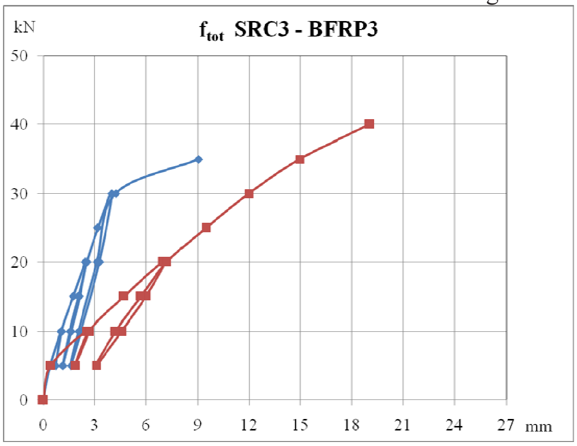


Fig. 7. The relationship load - deflection of the beam BFRP3 reinforced with basalt bars (squares), and for beam SRC3 with steel reinforcement (diamonds)

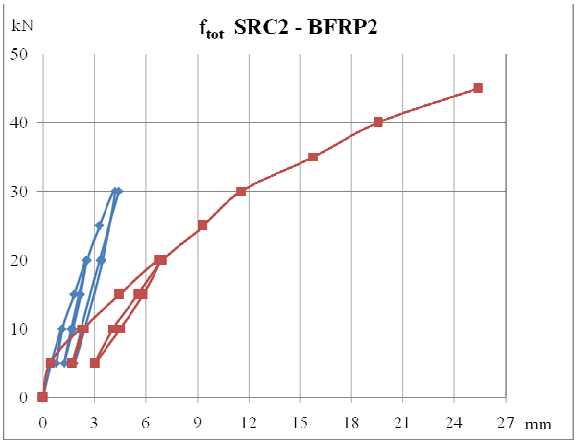


Fig. 8. The relationship load - deflection of the beam BFRP2 reinforced with basalt bars (squares), and for beam SRC2 with steel reinforcement (diamonds)

It can be seen the increased beam deflections with basalt reinforcement, compared to the steel bars reinforced beam. The reason for the larger values is a lower stiffness of beams reinforced with basalt bars in relation to conventionally RC beams.

Figure 9 shows a comparison of the average crack widths observed on the section of maximum bending moment for the BFRP beams with basalt reinforcement and one of the reference beams with steel reinforcement, as a function of the loading force.

For beams reinforced with basalt bars the average cracks width, depending on the load level, is 3 to 4 times higher compared to the traditional reinforced concrete beams.

Due to the much larger width of cracks in beams reinforced with basalt rods, compared to reinforced concrete beams, it is necessary to determine the appropriate minimum amount of reinforcement, which will reduce the width of the crack in bending.

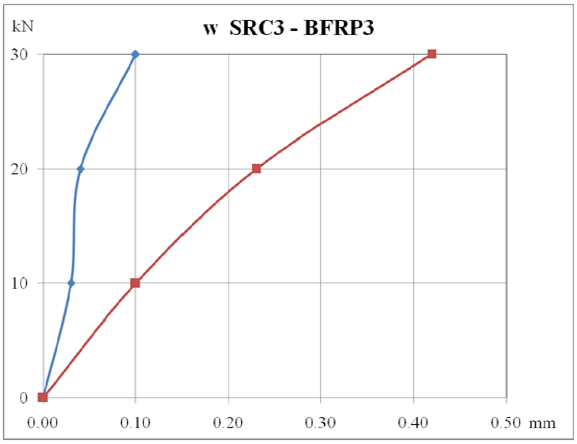


Fig. 9. The relationship average width of cracks - versus loading force on the sector of constant bending moment for beam with basalt reinforcement (squares), and beam with steel reinforcement (diamonds)

## 4. Conclusions

It has been stated in this study that in contrast to the bilinear stress-strain dependence for a steel reinforcement, basalt reinforcement has a linear dependence until the entire the beam section load capacity has been exhausted.

It was noted that critical load for tested beams reinforced with BFRP bars was much greater than the carrying capacity of beams with conventional steel reinforcement, which arose from the different degrees of mechanical reinforcement in both types of beams.

The failure of beams with BFRP reinforcement did not occur suddenly and this effect was a result of transformation of the beam into a tie system because of flexural basalt reinforcement remained unbroken.

Deflections of beams with BFRP reinforcement were significantly higher than the reference beam deflection, due to the much lower modulus of BFRP bars compared to steel bars.

Deformation of the reinforcement of concrete beams with basalt reinforcement were considerably higher (average of 3 to 4 times) than the beams with steel reinforcement. However, in the final phase of the loading the difference decreased to 40% due to the phenomenon of plasticity in the beams of conventional RC beams.

Average width of cracks on the section constant cross-section in beams with basalt reinforcement was 4 times higher than in the reference beams. Since the width of the cracks is primarily a function of the deformation of the reinforcement and the concrete between adjacent cracks, due to the much greater deformations in the reinforcement and the surrounding concrete with reinforcement for basalt beams, relatively to reference beams, the above phenomenon is as expected.

Due to the relatively lower elasticity modulus of basalt rods, compared to steel ones, both: the deflection and width of cracks can be a major factor in the designing the BFRP reinforced concrete beams.

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