Deflection of concrete slabs with GFRP reinforcement caused by shrinkage

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Abstract

The use of new reinforcing materials and products in the construction industry requires their thorough assessment for a variety of design situations. One of the significant effects is the shrinkage of the concrete, which in the case of asymmetrically reinforced elements can cause the element to be deformed. The research was focused on slabs asymmetrically reinforced by composite reinforcement (GFRP) and by three reinforcement stages. To eliminate the effect of concrete non-homogeneity, a concrete slab of the same dimensions was made of the same concrete. The results show a significant effect of shrinkage on reinforced slabs.

Key words: concrete shrinkage, slabs, deflection, steel and GFRP reinforcement

1 Introduction

In construction practice, new materials are constantly emerging and used, or other, unconventional uses of already known materials are being sought. At present, the design of concrete structures is heading towards the replacement of conventional steel reinforcement bars for non-metallic materials - fiber reinforced polymers (FRP). These modern trends of reinforcing in concrete load-bearing structures bring many areas that are not yet sufficiently explored. These also include the effect of concrete shrinkage on the deformation of concrete elements reinforced with composite FRP reinforcement.

At the Faculty of Civil Engineering of the Technical University in Košice, the influence of temperature on the behavior of elements reinforced with GFRP reinforcement has already been investigated [1]. Now we focus on the research of the effect of shrinkage on deformation and stress in elements reinforced by GFRP reinforcement (glass FRP). These are long-term tests aimed at measuring deformations and deflections of elements.

2 Long-term tests

To research the deformations of concrete elements caused by shrinkage, specimens of thin slabs reinforced at one surface were used. In the cross-section of thin slabs, there is minimal occurrence of stresses from uneven distribution of moisture across cross-sectional height [2]. Hydrating heat is uniformly lost from the cross-section, the temperature of the element is uniform [3]. The shrinkage deformations should also be uniform in cross-section. Due to the low ratio of concrete volume to surface exposed to drying in slabs, drying shrinkage can take significant value [3]. Due to the reduction of reinforcement shrinkage on only one side of the slab, uneven shortening of the surfaces results, resulting in a deflection caused by concrete shrinkage. At the same time, tensile stresses occur in the concrete which, if exceed the tensile strength of the concrete, can cause cracks formation [4].

2.1 Design of test elements

In order to compare the impact of the reinforcement on the stress of the concrete elements, it is desirable to examine elements with different reinforcement ratio (at least two levels). For the experiment, 3 reinforcement ratios ($\mu = A_r / A_c$) 0.3% (4 ϕ 8mm), 0.5% (7 ϕ 8mm) and 0.8% (7 ϕ 10mm) were selected (Table 1 - mechanical reinforcement ratio $\mu_m = A_r E_r / A_c E_c$) and two types of reinforcement: steel B500 (with modulus of elasticity 200GPa) and GFRP (with modulus of elasticity 50GPa). Six reinforced slabs and 1 reference non-reinforced slab with dimensions of 1800x600mm and thickness 120mm were made. There was used concrete with properties determined at 28th day: compressive strength on cubes 46MPa, cylindrical compressive strength 43MPa, flexural tensile strength 6.8MPa, splitting tensile strength 4.7MPa and modulus of elasticity 30.7GPa. The reinforcement cover was 10mm, transverse reinforcement ϕ 6mm at a distance of 200mm (Fig. 1).

Table 2: Amount and type of produced test specimens

Mark	Specimen (dimension)	Reinforce ment	Amount of reinforcement	Reinforce ment Area	Ratio $\mu = A_r / A_c$	Ratio $\mu_m = A_r E_r / A_c E_c$	Count
S1	slab (1800 x 600 x 120 mm)	Steel	4 ϕ 8mm	201mm ²	0,3%	1,8%	1
S2			7 ϕ 8mm	352mm ²	0,5%	3,2%	1
S3			7 ϕ 10mm	550mm ²	0,8%	5,0%	1
G1		GFRP	4 ϕ 8mm	201mm ²	0,3%	0,5%	1
G2			7 ϕ 8mm	352mm ²	0,5%	0,8%	1
G3			7 ϕ 10mm	550mm ²	0,8%	1,2%	1
UN		unreinforc	-	-	-	-	1

Figure 1: Forms with reinforcement ready to concreting

2.2 Methodology of long-term tests

On the seventh day after concreting, the specimens were removed and placed in a “chamber” to prevent sudden fluctuations in humidity and temperature during working in the laboratory. In order to eliminate as much as possible the influence of self-weight on the deformations and deflections of the slabs, the placement of the slabs in the vertical position (Fig. 2) [5] [6] was chosen. In this case, the self-weight of the slabs acts in the center plane of the slab and a very high cross-section resists acting moments. This results in very low stress (of the order of 0.02MPa) and deformations which can be neglected. With such a bearing, the deflection of the slab in the direction perpendicular to the center plane of the slab does not arise from the influence of the self-weight. In this way it was possible to observe the almost plain effect of concrete shrinkage on the deformation of the elements.

The layout of the points for measuring the deflection is shown in Fig. 3. The camber of the curved specimen, i. a. deflection in the center of the longitudinal sides that relates to their ends, was measured at the given points. All these deformations were measured using a steel frame equipped with dial gauges for direct deflection measurement [5]. Deflections were measured for 371 days (1 year after concreting) at intervals ranging from 3 days at the beginning to 2 months at the end of the reporting period.

Figure 2: Storage of specimens: 1- concrete slabs, 2- stand, 3- hang up, 4- slab reinforcement

Figure 3: The disposition of the points for measuring the deflection

3 Results

From the measured values of the displacements of the measuring points, the deflections of the slabs were identified, which are shown in Figure 4. Their development over time corresponds to the changes in the relative humidity of the environment at the place where the slabs are stored (Fig. 5). The slabs reinforced with steel reinforcement (with the largest amount of reinforcement) have the largest, slabs reinforced with GFRP reinforcement Armastek, respectively unreinforced slab have the smallest deflection. That corresponds to the mechanical degree of reinforcement ($A_r E_r / A_c E_c$) (Fig. 6).

Figure 4: Deflection in the middle of slabs

Figure 5: Relative humidity

Figure 6: Slabs deflection according to mechanical reinforcement ratio

Fig. 7 shows the deflection ratio of slabs reinforced by different types of reinforcement (same degree of reinforcement). At higher degrees of reinforcement, the deflection ratio is relatively comparable. GFRP reinforcement is active in preventing shrinkage all the time. However, at low levels of reinforcement, it seems that GFRP reinforcement initially does not prevent free shrinkage of the concrete at all. The influence of reinforcement (i.e. deflection) appears later, increases suddenly and gradually stabilizes (at the end of the period under review). Stabilization occurs at a value of approximately 2, so that the resulting deflection of steel reinforced slabs is 2 times greater than that of slabs reinforced with the same reinforcement ratio of GFRP reinforcement.

Figure 7: Deflection ratio of slabs reinforced by different types of reinforcement

4 Conclusion

The results of the experiment confirm the assumption of the influence of a different modulus of elasticity on the resulting deformations and deflections of slabs reinforced at one surface. It was found that the deflections of the steel-reinforced slabs are 2 times greater than the deflections of the GFRP-reinforced slabs at the same area of the reinforcement used at the end of the period under review. The deflection value from the shrinkage itself, e.g. for S3 (reinforced with $7\phi 10\text{mm}$ steel reinforcement), it constitutes up to 26% of the limit deflection (for ceilings), which is not a negligible value when assessing structures to the ultimate serviceability. In conclusion, the shrinkage of concrete has a significant effect on the resulting deformation of the structure.

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