Slab deformations caused by shrinkage – experiment vs. numerical calculation

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Abstract. This article gives an overview of the experiment, which aims to detect the effect of the shrinkage on the stress and the strain of the slabs reinforced at one surface by different types of reinforcement (steel and GFRP reinforcement). Some partial results from the strain measurements on steel reinforced slabs and their comparison with numerical calculation are also reported in the article. From publications found larger bending tensile creep towards compression creep can explain the difference between calculation and experiment.

1. Introduction

At the Faculty of Civil Engineering Technical University of Kosice, we investigate the effect of shrinkage on the strain and stress in reinforced concrete. Due to the implementation of new reinforcement types into practice, our goal is to determine the impact of these new reinforcement types, namely GFRP (Glass Fibre Reinforced Polymers) reinforcement. The main reason of different behaviour of GFRP reinforced elements is a significant difference in the modulus of elasticity in comparison to the conventional steel reinforcement [1, 2]. The results of the comparison of the proposed calculation model based on the theory of mechanics with the experiment for slabs reinforced by steel reinforcement are given in this article.

2. Description of experiment

2.1. Test samples

The slabs of dimensions 1800x600x120mm reinforced only at one side with different reinforcement ratio were used as test samples. The slabs were reinforced with a conventional steel reinforcement (3 specimens), GFRP reinforcement (5 specimens) and a reference sample of plain concrete (1 specimen). In this article compared slabs were reinforced by different amount of steel (B500) bars: 4ϕ8mm, 7ϕ8mm and 7ϕ10mm. The concrete cover was 10mm. Material characteristics of concrete were investigated experimentally. In 28th day were measured values: 43MPa for \( f_{cm} \), 6.83MPa for \( f_{ctm} \), \( f_{l} \) and 30.7GPa for modulus of elasticity.

2.2. Storage of samples

The slabs were demoulded on the seventh day and placed on the stands in a vertical position. This storage method has been chosen to maximally eliminate the influence of the self weight on the strains and deflection of the slabs (figure1). It is then possible in the other calculations to neglect generated stress and strain of the minimum values [3].
3. **Numerical calculation**

The reinforcement as a rheologically stable material prevents free concrete shrinkage, resulting in tensile stresses in the surrounding concrete and the pressure force $F_{cs}$ in the reinforcement [4].

$$ F_{cs} = -A_s E_t \varepsilon_{cs}(t, t_s) E_t $$

(1)

The stress created in concrete by this force:

$$ \sigma_c = F_{cs} \left( \frac{1}{A_t} + \frac{e_s}{I_t} \right) $$

(2)

Then the relative strain of the concrete is:

$$ \varepsilon_c(t) = \sigma_c / E_{cm} + \varepsilon_{cs}(t, t_s) $$

(3)

The values of strains $\varepsilon_{cs}$ measured on the surfaces of the unreinforced slab (reference sample) were used for calculation. Different values on both surfaces of the unreinforced plate are caused by non-homogeneity of concrete through the high of cross-section as a result of vibrating.

4. **Comparison of experimental results with numerical calculation**

In this manner calculated relative strains of concrete on both sides (A-side with reinforcement, B-without reinforcement) of slabs reinforced by steel reinforcement are compared with experimentally obtained values in figures 2-4 ($\varepsilon_{meas}$ = measured strain, $\varepsilon_{cal}$ = calculated strain, $\varepsilon_{unr}$ = strain of unreinforced slab).

On the graphs below, we can see that strain values calculated according to the theoretical assumptions of the mechanics do not correspond to the values measured on the samples during the experiment (difference 20-63%). These values are closing with the decreasing reinforcement ratio.
Figure 2. Comparison of calculation and experiment for RS1 slab (4ϕ8mm).

Such numerical model doesn’t correspond with measured values, so it was modified. The influence of creep was included:

$$\varepsilon_c(t) = \sigma_c(t) E_{c,eff} + \varepsilon_{cs}(t, t_s)$$ (4)
The resulting values changed only by 8-30%, which is not satisfactory enough. According to [5,6] the coefficient for the bending tensile creep of concrete is larger than the compression creep by a factor of 2-4 depending on load level and class of concrete. If we presuppose 2.5-times greater value of creep coefficient, we get comparable results (difference from measuring 1-4%) (figure 5).

![Figure 5. Comparison of calculation and experiment for RS1 slab (4ϕ8mm) using 2.5-time greater value of creep coefficient for calculation.](image)

5. Conclusion
From the performed calculations and their comparison with the experimentally measured values, it is clear that the chosen numerical model based on the theory of mechanics without creep influence is not suitable for determining the shrinkage strains of one-side reinforced slabs. The same model with creep influence gives better values, but not enough. The most appropriate results are given by model in which the creep coefficient was multiplied by factor 2.5. The finding of [5, 6] about larger bending tensile creep towards compression creep can explain the difference between calculation and experiment. But it is necessary find out how to predict the exact value of bending creep coefficient depending on many possible variables.

6. References
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