SIMULATION OF CORROSION OF REINFORCEMENT IN REINFORCED CONCRETE

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Abstract
In the frame of the research work APVT-20-012204, three reinforced concrete girder bridges were diagnosed. The results of the diagnostic will be used for modelling and investigation of the real traffic load effects. The modified reliability levels for the evaluation of existing bridges were used for their evaluation [1,2]. Here, the paper is focused on just one bridge, which is the most corrupted. This bridge was numerically modelled using software ATENA. The material characteristics needed for modelling were obtained by diagnostic.

The paper is concerned with detection and simulation of corrosion of steel reinforcement in the reinforced concrete [3]. The cracking response of the reinforced concrete beams due to the corrosion effect of the steel reinforcement was analyzed. The effect of corrosion was simulated by the nonlinear numerical analysis with the program ATENA [4,5].

1. INTRODUCTION

The paper presents the objectives and partial results of research work no. APVT-20-012204 “Remaining service life and increase of concrete structure reliability”. The optimum methods for increasing of existing concrete structure reliability by the application of the new technologies based on the technical diagnostics method, computer simulations and probabilistic evaluation of the concrete bridges, is the major aim of this project.

The attention of the project is paid to the project concentrates on existing concrete bridge structures, especially to bridge evaluation and the increase of reliability and serviceability for the remaining lifetime. There are always applied modern approaches to the structure reliability evaluation in practice in many countries. The new materials and technologies are used to increase the load carrying capacity and serviceability of concrete bridge structures as well. Many European standards concerning such problems are based on theoretical and experimental test issues.

For successive accepting of the European standards in Slovakia, the research of degradation factors on concrete structures, their accurate evaluation and new technologies are needed to increase the load carrying capacity and serviceability of structures.
2. SELECTION OF CRITERIA AND THE DESCRIPTION OF THE BRIDGE

The criteria for the bridge choice were determined in order to fulfil the aim of the research work. The criteria were focused on the kind of bridge (from the viewpoint of the superstructure type, faults occurrence, accessibility of the bridge), location, importance in the traffic network and adequate traffic action on the bridge.

Three reinforced concrete girder bridges satisfied the determined criteria. The bridges are in the village Kolárovice, on the road I / 18 over the Kolárovice river (Fig. 1).

![Figure 1: The location of the selected bridges in village Kolárovice and bridge superstructure.](image)

All bridges have similar parameters concerning dimensions, material quality and traffic load, but the reinforcement corrosion, dropping out the concrete cover and the significant bending and shear cracks were found just on bridge No. 3. Therefore, bridge No. 3 was selected for further investigation.

3. THE RESULTS OF THE DIAGNOSTICS

From the results of the bridge diagnostic follow that the type of the concrete is C 37 and the beams are reinforced by rebar of the type A (10210) in two layers (5φA30 in the lower layer and 2φA30 in the upper layer).

![Table 1: The measured values of geometric and material characteristics.](image)
Accordingly, the reinforcement corrosion was indicated. The corrosion caused the diameter loss from the initial value of 30 mm to the actual average value of 29.3 mm (the minimal measured value is 28.7 mm) and caused the dropping out the concrete cover. The concrete cover was 30 mm. The measured values of geometric and material properties concerning all girders and slab are shown in Table 1.

4. PROBLEM DESCRIPTION

The reinforced concrete shows much higher strength and mainly durability in compare with other building materials. This material does not need any protection against effects of external environment in generality of cases. Concrete by itself usually warrants adequate protection of reinforcement against effects of aggressive environments.

It is possible to classify the corrosion of reinforced concrete components into two major sections. In the first section, the damage of concrete cover of bars in concrete becomes. Consequently, the corrosion of steel reinforcement appears. The corrosion in second section does not come because of damage of concrete cover in concrete, but it appears by its chemical modified form effects on steel. The damage of the concrete is caused by stress in lateral tension, which accrues from product of reinforcement corrosion (fig. 2). This damage of the concrete has mechanical character and the paper deals with this mechanical character by simulation of corrosion in the reinforced concrete beams (laboratory specimens).

In our case, the cracking response of the reinforced concrete beams due to the corrosion effect of steel reinforcement was analyzed. The response of the concrete section, namely the crack propagation and the crack width, was monitored.

The schema of reinforcement placing and dimensions of beams is shown in figure 3.

The cross-section of beams was also numerically simulated in the program Atena. For laboratory specimens and for numerical modelling was used:
- steel reinforcement of type 10 216,
- steel reinforcement of type 11 333 with pipe cross-section.

The bar diameter was 6 mm for both.
Figure 3: Schema of reinforced concrete beams.

The effect of corrosion was simulated by the prescribed volume expansion of the steel reinforcement known from the experimental measurements of steel reinforcement corrosion process in the reinforced concrete beams.

The imposed volume strain was specified in the reinforcement as a loading and was uniformly distributed within the cross-section of the reinforcement. This strain was incrementally increased in a series of the load steps.

The concrete was modelled by the SBETA material model based on the crack band theory and the fracture energy. The reinforcement bar was modelled as elastic material. The interface between steel reinforcement and concrete was modelled by element 2D interface.

The size of the mesh elements was in average 3 mm (fig. 4). In the middle of top part of cross-section we monitored the crack propagation and the crack width (black point – fig.4).

Table 2: Basic parameters of beams.

<table>
<thead>
<tr>
<th>Type of reinforcement</th>
<th>Diameter of reinforcement (mm)</th>
<th>Elastic modulus (N/mm²)</th>
<th>Compressive strength (N/mm²)</th>
<th>Tensile strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 216</td>
<td>6,0</td>
<td>30 000</td>
<td>25,0</td>
<td>2,3</td>
</tr>
<tr>
<td>11 333</td>
<td>6,0</td>
<td>30 000</td>
<td>22,5</td>
<td>2,2</td>
</tr>
</tbody>
</table>

Figure 4: Finite element model.

5. RESULTS

The process of the crack propagation in reinforced concrete beam with steel reinforcement 10 216 is in the figure 5 (5 phases of loading).
The crack propagation was running from the centre to the edge of the cross-section till the damage of complete reinforced concrete cross-section of the beam.

Figure 5: Crack propagation in a series of load steps.

Figure 6: Crack width in individual analysis steps.
6. CONCLUSIONS

The main aim of the presented work was to model how the reinforced concrete beams were influenced by reinforcement corrosion and to capture the crack width of concrete at peak of the load-deflection diagram. The calculated results were compared with the measured results (fig. 6). The maximal measured crack width in monitored cross-section with reinforcement 11 333 was 0.65mm and the maximal crack width with reinforcement 10 216 was 0.60mm. The maximal calculated crack width in cross-section with reinforcement 11 333 was 0.5685mm, in the case of reinforcement 10 216, the maximal was crack width was 0.5045mm in the 5th phase of loading.

In conclusion, from achieved results follow that the reinforced concrete beam with reinforcement 11 333 had bigger crack width than the reinforced concrete beam with steel reinforcement 10 216. By calculated and measured values, it is seen a satisfactory conformity between results.

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REFERENCES