The application of the finite element method for the modeling reinforced concrete elements with pre-organized cracks

A Kurbonov, F Sametov and V Mitasov
Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Leningradskaya st. 113, Novosibirsk, 630008, Russia

ajamy9009@gmail.com

Abstract. Early cracks prevention and their further development is one of the main tasks of scientists conducting research on concrete and reinforced concrete structures. The study of these problems is a very complicated process, requiring a long time and material costs. In this regard, the constantly evolving software complexes of numerical simulation provide great opportunities to obtain calculation results close to experimental ones, as well as significantly reducing the time and material costs. In this article, we analyze the results of modelling the reinforced concrete elements behavior with organized pre-cracks under the action of static short-term loads. Simulation is performed with the ABAQUUS (version 6.14) software.

1. Introduction
Concrete as a modern building material is the most widely used one. It has a number of advantages, such as, accessibility, simplicity of the manufacturing process, good fire resistance, lower cost, etc.

Despite of this fact, the concrete still remains as a vulnerable one to early cracking of varying degrees and different shapes in the stretched zone during operation and even construction process, which reduces the durability of the concrete structure, with a reduction in its service life.

In this case, both in Russia and abroad, the research is being conducted to develop and improve the method for calculating the stiffness of reinforced concrete bending elements with cracks in operation [1, 2], the influence of previously existing cracks on the strength of the reinforcement bonding to concrete is studied [3, 4], fracture forecasting in reinforced concrete structures is conducted [5].

Recently, several experimental studies were carried out in the samples manufactured using traditional technology with pre-arranged cracks within the framework of the reinforced concrete resistance theory, previously presented by professors Mitasov V.M. and Adishchev V.V. at Novosibirsk State University of Architecture and Civil Engineering [1, 6].

2. Materials and methods of experimental research
Two series of reinforced concrete beams with cubes and prisms were manufactured for the research. All samples were made with the same geometric dimensions from fine-grained concrete with B15 class strength, and with the same A400 class reinforcement with 8 mm diameter. The organized cracks were formed by the installation of 0.3 mm thick and 35 mm high aluminum plates in the sections of the element stretched zone.
The objects of the study were 6 beams, namely three samples of continuous section; three were with three organized crack in the middle of the span (Figure 1).

A scheme of an articulated single-span beam loaded with one concentrated F force applied in the middle of the span was adopted as a design scheme for testing bent samples. The percentage of reinforcement was 0.5%, the protective layer was 35 mm.

![Figure 1.](image)

**Figure 1.** Reinforced concrete samples for the model experiment: solid beam (a); beam with an organized crack in the middle of the span (b), 1 – organized crack.

3. **Nonlinear modeling in the Abaqus software**

The following factors of nonlinearity are taken into account in the ABAQUS program [7] when solving nonlinearity problems: physical nonlinearity; geometric nonlinearity; nonlinearity of boundary conditions.

Also, the concrete models with cracking and concrete fracture are considered in this software complex. This is a spread model, which involves the cracking process in any zone of the element where the stresses in the concrete reach one of the surfaces or in the biaxial stretching area and the model of concrete (CDP) plastic fracture, which is well-known and used in the finite element method for single cyclic and dynamic loading.

The concrete is modeled by the C3D8R volume element, and the rod-shaped armature is T3D2 element. The adhesion between concrete and reinforcement is modeled with the embedded technology as a rigid connection taking into account the coefficient of friction between concrete and reinforcement.

A reinforced concrete beams with dimensions of 1.1×0.14×0.07 m, without cracks (Figure. 2) and with 3 initial cracks (Figure. 3). The cracks were modeled in the tensile zone of the beam with dimensions of 0.01×0.035 m.

4. **Analysis of the numerical simulation results**

Data obtained from the numerical simulation results are comparable with the data of previous experiments. The results show that the stress-strain state in stressed beams with organized cracks is qualitatively and quantitatively different from that in the beam without cracks. When the stresses in the stretched zone are 94% of $R_{ct}$ (concrete tensile strength) a significant number of stochastic cracks have aroused in beams without organized cracks. And stochastic cracks are formed in beams with organized cracks only near the simulated cracks (Figures 4, 5).

The deflections of beams with or without organized cracks are showed in Figures 6, 7. As expected, the deflection of the beam with the organized cracks turned out to be less than the deflection of the beam without cracks (the difference was 22%), which is quite comparable with the result of a physical experiment.
Figure 2. Reinforced concrete beam without a crack.

Figure 3. Reinforced concrete beam with 3 organized cracks.

Figure 4. Scheme of crack formation in a beam without organized cracks.

Figure 5. Cracking scheme in a beam with 3 organized cracks.
5. Conclusion
The method of numerical modeling in the ABAQUS software using the example of reinforced concrete beams with or without organized cracks was considered in this article.

In this software package, as the study showed, it is possible to model reinforced concrete elements in which their physical properties and behavior during deformation and cracking are closest to the result of the experiment. In ABAQUS software, as the study showed, it is possible to simulate reinforced concrete elements in which their physical properties and behavior during deformation and cracking are closest to the results of the experiment.

Based on the results of numerical simulation, the following conclusions can be drawn:

- The beam with organized cracks shows the smooth nature of the deflections dependence on the load.
- The number of stochastic cracks that arise is noticeably smaller in a beam with organized cracks, than in a beam without a crack.

Acknowledgment(s)
The research materials publishing was supported by the NSUACE (Sibstrin) internal grant #18-06.04.48 from 04.06.18.
Figure 8. Load-deflection curves.

References

[1] Mitasov V M and Adishchev V V 2010 News Higher Educ. Inst. Const. No 6 3-8
[2] Liu Jing-Song and Liu Hong-Jun 2009 J. Equip. Manufac. Tech. No 6 69
[3] Jankowiak T and Lodygowski T 2005 J. Found. Civil Envir. Eng. No 6 53-69
[4] Yuan J, O’Reilly M and Matamoros A 2016 ACI Struct. J. 113 801–12
[5] Chaudhuri SV and Chakrabarti M A 2012 Int. J. Comp. Appl. 44 No 7 28-32
[6] Michailova N S 2007 News Higher Educ. Inst. Construc. No 4 110-3
[7] Willam K J and Warnke E D 1975 Constitutive models for the triaxial behavior of concrete
   Proc. International Association for Bridge and Structural Engineering Vol 19 (Bergamo: ISMES) p 174-91