Bionic Structures for Innovative Concrete Slabs

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Summary

The adaption of natural structures in technical systems leads to highly efficient and sustainable constructions. This scientific paper presents results of a research project financed by the German Science Foundation considering the design process, the nonlinear simulations and the experiments of two developed bionic slab structures. The bionic concrete structures are optimized by use of evolutionary algorithms. The developed models are tested in large scale experiments at the University of Duisburg-Essen.

Keywords: Bionic; Structural Concrete: Optimization; Reinforcement Configuration; Slabs

1. Introduction

Constructions using natural archetypes ideally lead to lightweight-bearing systems, which have a natural flow of forces. The investigations of lightweight bearing slabs inspired by natural structures is a project, which is part of a DFG (German Research Foundation) Priority Programme (SPP 1542). In the presented research results, the influence of adapted natural structures to the load bearing behavior of biaxial slabs is shown. Two innovative structures including the optimization process, results of the linear and nonlinear simulations and the experimental tests of these two bionic structures are presented. The shown structures are (a) spider webs as base for an innovative reinforcement configuration and (b) geometries and forms of natural structures for the optimization of ribbed slabs. For the development of bionic concrete structures evolutionary algorithms (an adaption of the biological evolution process) were used in combination with linear and nonlinear finite-element simulations.

For the development of bionic structures several methods can be chosen. At the Institute of Structural Concrete at the University of Duisburg-Essen (IfM), scientists use an evolutionary algorithm (called GPCore) based on genetic programming [1]. It was developed at the IfM and successfully used to solve several optimization problems. In the following, two bionic structures will be presented, which are being developed and optimized by using GPCore. After the form finding process, the developed structures were tested in a large scale test at the IfM.

2. Research Results

The first bionic structure that has been worked out at the IfM, is a reinforcement configuration based on the functional principle of a spider web. The innovative reinforcement structure was developed during an optimization process using GPCore. The quality of the slab (fitness) is characterized by the middle deflection of the slab as a function of the total length of the installed reinforcement per each slab. As a reference value, the results of conventional orthogonally reinforced concrete slabs with a comparable reinforcement ratio were used [2].

During the optimization phase, the form finding process led to an optimized configuration that was confirmed over a variety of generations. The developed reinforcement configuration includes a radial base reinforcement and two tangential reinforcement areas with a constant distance of the tangential rebars. This configuration of the reinforcement is shown in Figure 1.

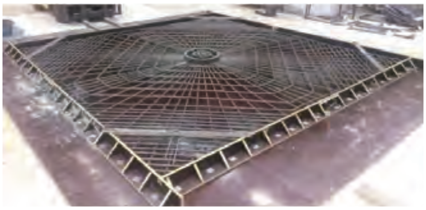

Fig. 1: Reinforcement Configuration (300 m total length of rebars; $\phi = 10$

In nonlinear simulations the optimized structure with ideal conditions shows an improved load bearing behaviour compared with a reference slab orthogonally reinforced with a comparable reinforcement ratio. At the same load, the developed structure suffers a smaller deformation than the reference slab. The experimental results show a high ductility in the plastic region for the developed reinforcement configuration. The load-deformation behavior of the slab has improved over 90% of the load history.

The second bionic structure is developed analogous to the profiles of natural structures. The optimization process for the arrangement of an improved rib structure is divided into two phases of optimization. In the first phase the influence on the arrangement of radially oriented ribs on the bearing capacity was tested out. Concerning the number of ribs, the height and width of the ribs and the height of the slab served as optimization variables. A conventional reference slab is used in order to evaluate the quality of the results.

The properties of the top rated structures were used to the further development in the second optimization run. In this process, similarly to the natural structures of the giant water lily, transverse ribs were arranged between the radial ribs, which led to an improved system. These bionic rib structures were simulated with the FEM and evaluated depending on the deformation and the use of materials (concrete and steel). The developed structure, which was selected as base structure for the further experimental test, has an improved fitness of 25% to the conventional reference structure.

The large scale test shows the improved bearing stiffness in relation to a reference slab with identical material usage. A shear crack at a rib predicts the collapse of the innovative ribbed slab.

3. Conclusion

The development and the use of bionic structures can influence and improve the load bearing behavior. Therefore, sensible optimization and adaptation processes were carried out. In this paper, a research project was presented, in which two different bionic structures have been examined and adapted for structural concrete.

The first developed structure is a bionic reinforcement configuration. By adapting principally stress oriented reinforcement configurations based on the functional principle of the spider web, a very ductile component behavior could be reached before the collapse. Under the given boundary conditions, the deformation behavior was improved, in relation to the behavior of a reference slab, for over 90% of the total load period. The second presented structure is an innovative ribbed slab inspired by the forms and shapes of a water lily. In comparison to a reference solid slab with similar use of material, the developed bionic ribbed slab achieved an increased bending stiffness with a higher ultimate load.

4. References

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