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Design Optimization in Statics of Structures and Aesthetics of Structures

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***Abstract*:** *The interdisciplinary contribution combines objectives of statics and architecture. The goal of the paper is to show that the optimal design of structures leads automatically to aesthetic structures. The optimal design can be based on empiricism, experiences, on theoretical knowledge: mathematics-mechanics-structure and optimization methods.*

Keywords: *structures, statics, design, optimization, aesthetics*

1. Introduction

Civil engineering and architecture develop parallel thousands of years in close connection. Technical requirements and aesthetics are often considered separately, what is in general wrong. The technology can communicate with art. In this contribution we would like to point out that the optimal design of bearing structures leads automatically to aesthetic results. Under optimally designed structure in statics we understand a structure which fully uses the material. The material is placed only there where is needed. The optimally designed structure does not need any added esthetic objects and despite of this is beautiful. We will try to explain why. The optimally designed bearing structure evokes in humans the sense of safety. Optimal proportions of objects induce in humans a sense of comfort.

Of course, the optimal design has to respect the boundary conditions, the loading and the type of used material, its properties and technological conditions of structural elements.

Under the boundary conditions we understand for example points of support.

The loading in civil engineering includes the dead load, wind load, snow and seismic loads.

Materials used commonly in bearing structures are: concrete, steel, wood and modern materials e.g. glass, smart materials as well. In some cases, the combination of materials in the construction is efficient e.g. concrete in compressed part of the structure and steel in tensioned part of the structure.

The optimal shape of the structure can be a result of the long time development based on experience. The shape of the structure in civil engineering can be created on the base of analogies with shapes in the nature. The shape of the structure can be also the result of the computer optimization. Mathematical optimization applied to a structure has different levels: topology optimization, shape optimization and optimization of the cross sections. In this sequence an aesthetic result can be reached with help of computer – without aesthetic feeling. The contribution provides optimized structural systems which have high aesthetic level mainly thanks to geometry.

2. Optimal Design Based on Statics

The design of structures in statics is based on equilibrium principle (see Figure 1).

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Fig. 1: Equilibrium of forces in nodes, equilibrium in supports, Vancouver.

Parabolic shape results from assumption of uniformly distributed vertical load (see Figure 2).


Fig. 2: Parabolic shape of bridge in Bratislava.

The optimal shape of some structures can be achieved on the base of the principle of minimum potential energy (see Figure 3).

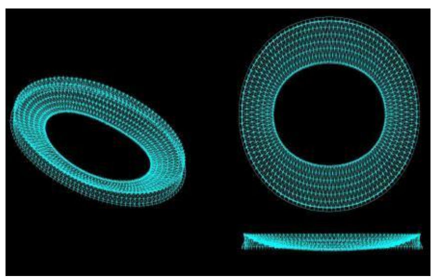
Fig. 3: Shape of Vienna Prater stadium roof model resulted from principle of minimum potential energy.

3. Optimal Design - Inspiration from Nature

The evolution in the nature resulted optimized structures. We can draw inspiration from the natural structures [2], [5] (see Figures 4 and 5).


Fig. 4: Tree supports of Stuttgart Airport Terminal

Fig. 5: Glass and carbon fibers structure of research pavilion ICD/ITKE, Stuttgart.

4. Mathematical Optimization

Under optimally designed structure we understand a structure which fully uses the material. In structural optimization we can distinguish three levels: 1. Dimension optimization, 2. Shape optimization and 3. Topology optimization. The order of levels reflects the historical development. The reverse order corresponds to the sequence applied in practice-oriented design.

4.1. Dimension Optimization

In statics designers commonly perform the dimension optimization of structures step by step. The dimension optimization can be automated using mathematical programming methods and evolutionary procedures. Example of changeable cross section in the structure illustrates the application (see Figure 6).

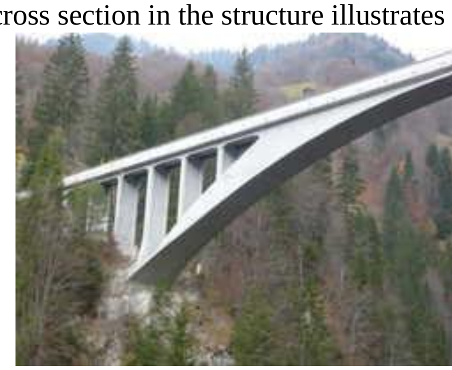

Fig. 6: Salginatobel Bridge – changable cross section.

4.2. Shape Optimization

The expansion of the shape optimization occurred when the discretization methods in mechanics reached a sufficient level of development. The shape optimization is the most frequently applied on the finite element model of the structure. Figure 7 shows result of shape optimization.

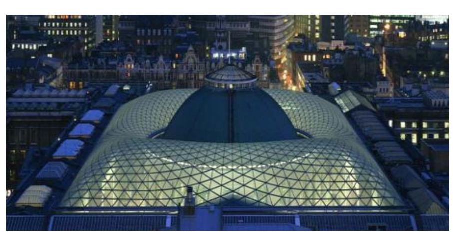

Fig. 7: Roof structure of the British Museum London.

4.3. Topology optimization

Topology optimization is a mathematical approach that optimizes material layout within a given design space, for a given set of loads and boundary conditions [4] such that the resulting layout meets a prescribed set of performance targets [1]. Last decades the optimal topology replaces the experience gained during many years [3]. Nowadays the topology optimization is a modern tool for design of new types of structures. Figures 8 and 9 illustrate the optimized topology.

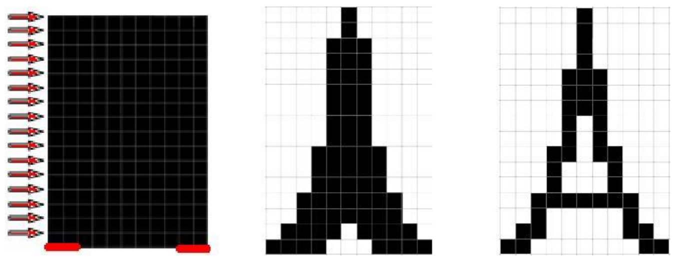

Fig. 8: Max stiffness - Topology optimization - initial and optimized: tower (rough mesh)

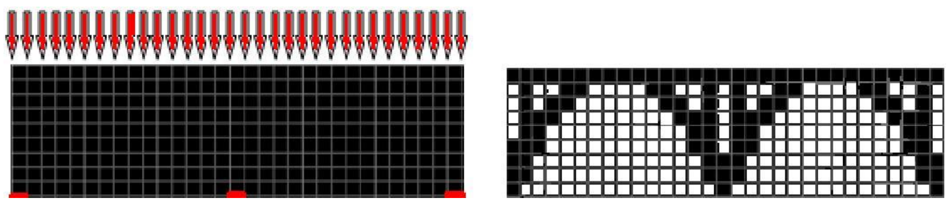

Fig. 9: Max stiffness - Topology optimization - initial and optimized: bridge (rough mesh)

4.4. Mathematical optimization procedures

Mathematically the optimization of structures can be posed as the problem of finding a bounded set of variables minimizing an objective function. The most used optimization procedures are: method of moving asymptotes, optimality criteria method and genetic algorithms. Genetic algorithms are most universal for a wide set of optimization problems in structural design.

5. Summary

Optimal design of civil structures results in art, which can people feel and admire.

6. References

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