ON IMPLEMENTATION OF SUBDOMAIN ORIENTED TOPOLOGY OPTIMIZATION INTO STRUCTURE RETROFITTING

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1. Motivation

Nowadays, restoration processes have ability to enjoy the benefits of all innovations proposed in science and engineering. In what follows up-to-date retrofit designs can be obtained based on efficient numerical methods, including optimization ones. This paper is focused on one of the new concepts, namely implementation of topology optimization into retrofitting of structures suffering from the effects of structural damage and material degradation. Topology optimization allows to obtain stiffer, lighter and cheaper constructions preserving their aesthetic value by developing new, original shapes of strengthening.

2. Problem

Some important aspects of retrofitting and strengthening of existing structures have been reported in literature and the books [1], [2] may serve here as examples. This paper considers a new point of view, namely adaptation of topology optimization techniques to searching for the optimal layout of strengthening elements to be implemented into damaged and/or weakened structures. The idea is to implement a random stiffness information of the original structure into the optimization process. It can be done, by modelling design-passive regions with randomly distributed values of material data. The randomized stiffness distribution within weakened structure is modelled in order to include effects of material degradation. As a result, the new layout of strengthened structure of maximum stiffness for which the assumed volume fraction is preserved can be obtained. This approach allows to reduce a mass of strengthening elements, but what is essential, the complete and detailed information about the material degradation level of the original structure is not required to perform the optimization process.

In the problem formulated in this paper, two possible interpretations of objective function are taken into account. Firstly, it can be interpreted as a minimization of a compliance of the construction as a whole, where the design domain is only a part of the structure. Second way is to interpret the objective function as a compliance calculated only for the domain where the optimization process is performed. This approach is understood as a subdomain oriented topology optimization.

As the efficient topology generator the algorithm based on Cellular Automata concept developed by the Authors [3] has been used.

3. Results

In order to illustrate the above proposed approach, the subdomain oriented topology optimization of the bridge structure shown in figure 1 has been performed.

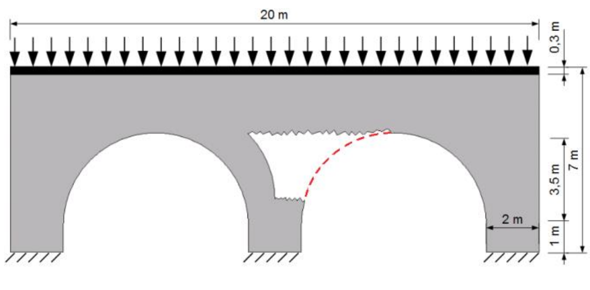

Figure 1: Damaged bridge structure with applied loads and supports.

It has been assumed that the bridge has been weakened by both structural damage and by the effect of material degradation. The upper part plotted in black colour is representing a road, this part is excluded from optimization. The Young modulus of the original material equals E =27 10^9 Pa.

Two models of a weakened material are considered. The first one it is uniformly distributed material of decreased, as compared with the original structure, value of the Young modulus. The constant value of 0.9 E has been selected. In the second model of the weakened material the Young modulus values are randomly selected from the interval: 0.8 E – E. The material degradation is illustrated in the figure 2a by randomly distributed green/grey regions. Performing optimization process within the selected design domain results in creating a topology of strengthening which minimizes the total structure compliance. In the figure 2b a visualization of expected optimization result is presented.

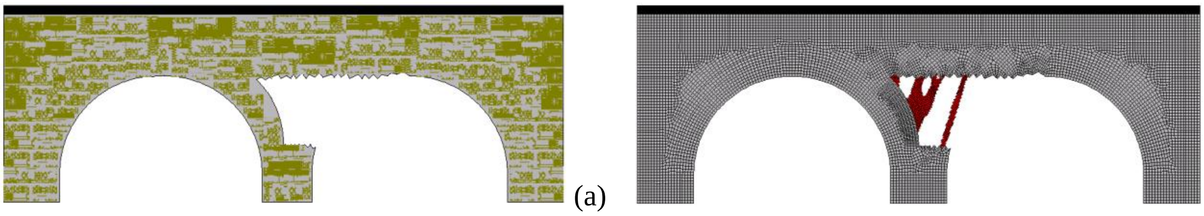

Figure 2: Randomly distributed weakened material (a), strengthened structure (b).

As the first task, the topology optimization has been performed for the damaged structure with uniformly weakened material. The Young modulus of a material in the domain selected for optimization equals E. The value of distributed load is 1000 N/m whereas assumed volume fraction of material for resultant, optimized topology within design domain equals 0.25. It is worth noting that structural damage caused significant increase of compliance from 0.01426 Nm calculated for original perfect structure to 0.03007 Nm. The further increase of compliance to 0.03322 Nm results from material degradation towards 0.9 E. In the figure 3 the obtained topology optimization results are presented. The total compliance has been reduced to 0.01871 Nm (a) and to 0.02031 Nm (b), respectively.

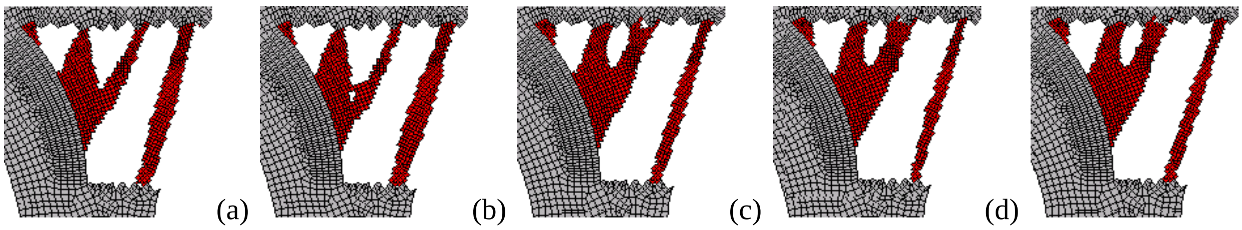

Figure 3: Topologies of strengthening: (a) uniformly distributed original material E, (b) uniformly distributed weakened material 0.9 E, (c)-(e) randomized distribution of weakened material 0.8 E – E.

The topology optimization procedure has been applied next to three different cases of random distribution of a weakened material (0.8 E – E) to check to what extent randomized values of the Young modulus influence final designs. Figure 3 presents topologies generated for all three cases for which compliance values are: (a) 0.02051, (b) 0.02112 and (c) 0.02061 Nm. It is worth noting that the results obtained for different randomizations are very similar, which means that there may exist a representative topology for the proposed random model of weakened material. To conclude, in all discussed cases the implemented retrofitting procedure allowed for a significant reduction of structure compliance what confirms the efficiency of the presented approach. It can be treated as a basis for developing novel design techniques for strengthening of existing structures suffering from the effects of structural damage and material weakening.

References

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