# Topology optimization of steel-box girders in cable supported bridges

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Current state-of-the-art methods for the design of supporting structure in very long cable suspended bridges, i.e. the orthotropic steel box girders, have not changed significantly since the 1960's. Furthermore, a recent study, based on highly advanced numerical models combined with sizing optimizing methods, concludes that the current design is bound by a maximum reduction in mass of 13%[1]. As self-weight is now the limiting factor in the pursuit of even longer cable suspended bridges, this means that the current box girder design prohibits the construction of bridges with very long free spans, e.g. a span covering the strait of Gibraltar. Hence, a complete redesign of the steel box girder is necessary to overcome the limitations imposed by the 50+ year design methodology. Another relevant aspect, motivating the redesign and possible weight reduction of such large-scale structures, concerns the carbon footprint of the construction industry, which currently comprise 39% of the world's $CO_2$ emission.

The main objective of the work presented here is to explore new and innovative box girder designs using the material distribution technique known as topology optimization. Supported by the PRACE grant TopBridge, this was investigated on the Joliet Curie-SKL@GENCI facility in France building on a base code developed during a previous PRACE project TopWing[2]. The need for HPC in order to solve this design task was due to the following reasons. First, in order to capture the structural details in the current box girder design, a resolution of minimum 2 billion voxels was necessary. Secondly, to make the results practical applicable, a 12-fold symmetry mapping had to be computed and applied in parallel using more than 16.000 cores. Furthermore, the number of dominating load cases was found to be no less than five and moreover, the resulting optimization problem is no longer self-adjoint. This means that for every design cycle a total of ten PDE systems had to be solved (five forward and five adjoints) which significantly increased the computational effort needed. The final major obstacle concerned the extreme low volume fraction, i.e. ~1.5%, which required new convex separable optimization solvers to be developed.

The final outcome of the TopBridge project is a novel, yet simple, interpreted box girder design with a 28% reduction in mass compared to the conventional design. We remark the interpreted box girder design is only slightly more complex to manufacture, and hence, that a low cost for its construction is ensured. Thus, the TopBridge project has paved the way for longer and more environmentally sustainable cable supported bridges.

References

1. Baandrup, M., Noe Poulsen, P., Forbes Olesen, J., & Polk, H. Parametric Optimization of Orthotropic Girders in a Cable-Supported Bridge. Journal of Bridge Engineering, 24(12), 2019.
2. Aage, N., Andreassen, E., Lazarov, B. S., & Sigmund, O. Giga-voxel computational morphogenesis for structural design. *Nature*, *550*(7674), 84–86, 2017.