Cable-Stayed Bridge Optimization Solution Space Exploration*

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João Correia
University of Coimbra, Centre for Informatics and Systems of the University of Coimbra, Department of Informatics Engineering
Coimbra, Portugal
jncor@dei.uc.pt

Fernando Ferreira
Matereo
Coimbra, Portugal
fernandoferreira@matereo.com

Catarina Maçãs
University of Coimbra, Centre for Informatics and Systems of the University of Coimbra, Department of Informatics Engineering
Coimbra, Portugal
cmacas@dei.uc.pt

ABSTRACT

In this work, we explore and optimise solutions for a controlled cable-stayed footbridge with a pre-determined length and width. The problem consists of designing a complete and cost-efficient bridge solution with geometry, cross-section, prestress and control design variables. The dynamic and static constraints create a deceptive landscape of the solution space, which, in turn, makes this problem hard to optimise via standard optimisation. We start with a conventional Genetic Approach and show that we are able to fulfill the structural requirements. Afterwards, we move to explore the variables and conditions that enable us to traverse in the solution space, optimising structural requirements while lowering the cost of solutions. The results present the sensitivities for all design variables for the baseline solution. We observed that most design variables could not be changed in any direction without compromising the structural constraints or cost. The results demonstrate that the optimisation of cable-stayed bridges requires finding a very delicate balance between multiple structural constraints and cost, which poses an interesting benchmark problem for the use of evolutionary algorithms in structural optimisation.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability;

KEYWORDS

Genetic Algorithm, Iterated Local Search, Local Search, Solution Space exploration, Bridge design, Structural Design

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1 PROBLEM DEFINITION AND RESULTS

The problem definition is based on previous works available in the literature [2, 3] which evaluation function had been made available to perform this work. The presented approach can be adapted to the point that some of these constraints can be included in the set of Design Variables (DVs) (more details in [1, 2]). In this work, we fixed the size of the bridge to 220 meters and we are using a baseline solution optimised using a conventional gradient-based approach from the work of Ferreira and Simões [2] as reference which has the following optimised solution:(i) Bridge cost: 91.354 k€ and; Max Structural Constraints value: 0.9962. Thus, we want to explore solutions that minimise the max structural constraints value, while looking into the cost which should be lower than a reference value, which for the size of the bridge is set to 150k€. We explore both the iterated local search and Genetic algorithm based on experiments from [1] and more information about all the experiments can be found at https://cdv.dei.uc.pt/evocbs.

In figure 1 we show the results of the exploration via iterated local search starting for the baseline. The baseline solution satisfies the Pareto optimal criteria with the exception of DV10. It is not possible to change any DV without compromising at least one criteria or the cost. Nonetheless, it is possible to improve the baseline solution by using further approximations, as the worse value for the structural constraints for the baseline solution was 0.996 and the solution could be improved by reducing the cost until this value is closer to an unitary value. A thorough analysis can be found at https://cdv.dei.uc.pt/evocbs.

In figure 2 we can observe the plot of all points from this exploration, under different interval of values, i.e. regions of interest. The figure 2 bottom scale represents the region of solutions that could be considered from a structural engineer perspective with the c_r of 150€k described, although the value for structural constraints should be closer to 1.0. The DV variat. are the points from the variation of the DV with the iterated local search method. The Best optimized is the solution found via conventional optimized hands-on approach. The Individuals are all the points from the evolutionary runs. The Best Ind. (1st); Best Ind. (last) represent the best solutions in the first and last iteration respectively. The Best Ind. (all) are all the best solution found per generation per all the evolutionary runs performed. The Average Vals points are points from the average run, obtained by computing the average per generation of all the evolutionary runs.

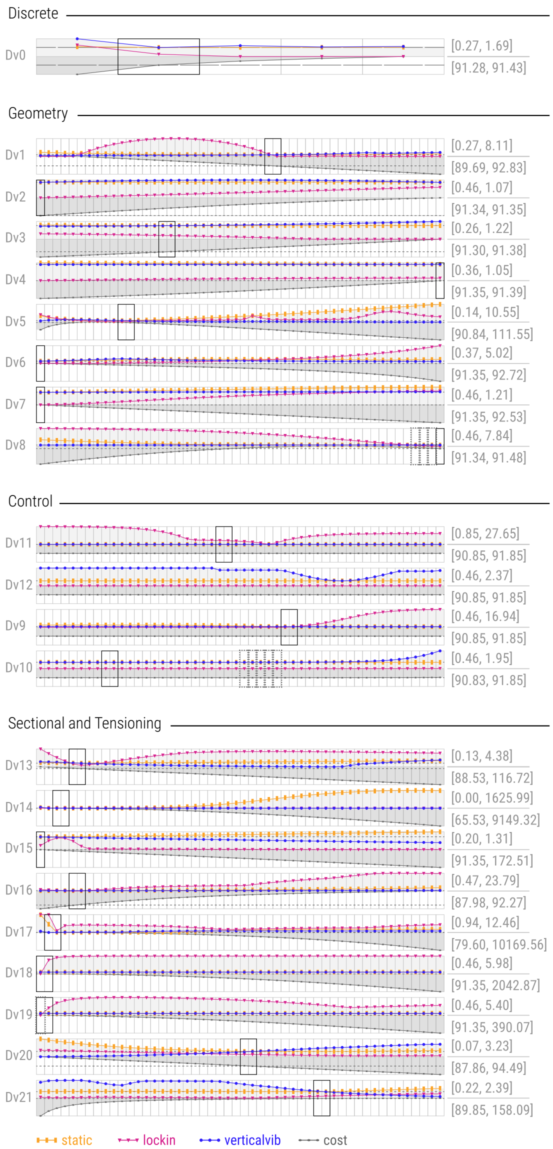

Figure 1: Design variables. Each DV has two y-axes with opposite directions: (i) from centre to top (light gray area) is the structural constraints axis; and (ii) from centre to bottom (dark gray area) is the cost axis. Each y-axis has an individual scale presented on the right of the graphic. The x-axis represents each iteration of the local search. The horizontal dashed lines represent the reference values of the best optimized solution.

2 CONCLUSIONS

The optimum design of Cable Stayed Bridge (CSB) can be viewed as a relevant benchmark for optimization algorithms as it requires to consider both the geometry, cross-section, cable tensioning and control devices to address the real-world problems. We provided an analysis of the solution space of this problem under structural and cost constraints, using iterative variation of existing solutions and

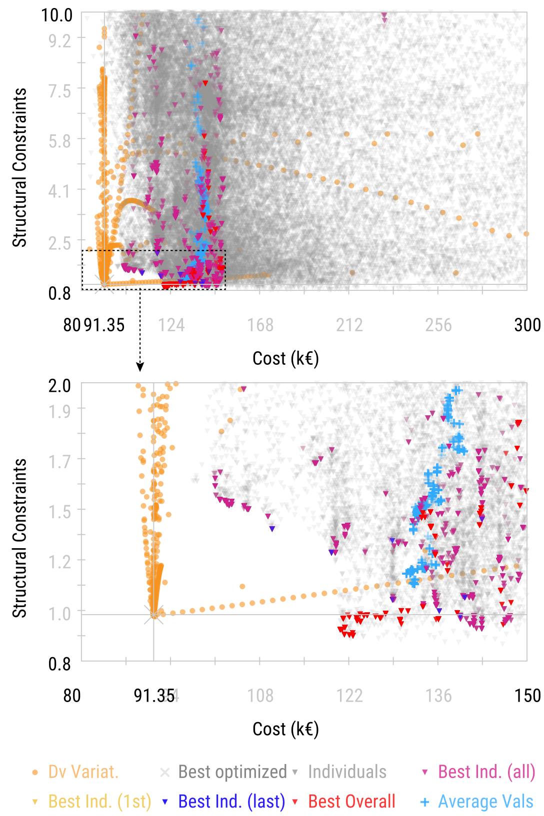

Figure 2: Scatter plot of the different pairs of structural constraints values (yy) and cost values (xx) for different points of the experiment. All points from the experiments that are contained in the axis scale are represented in this graph. In the bottom, the scatter shows closeup on the best optimised solution.

using a Genetic Algorithm (GA). The results suggest that the problem has complex and deceptive dynamics and we are conducting further experiments to deploy it has an optimization benchmark problem.

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