Multi-parametric MINLP optimization study of a composite I beam floor system

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A B S T R A C T

This paper deals with a comparative study of an optimal design regarding composite steel and concrete floor structures based on the performed multi-parametric mixed-integer non-linear programming (MINLP) approach, and Eurocode specifications. The optimization models COMBOPT (COMposite Beam OPTimization) were developed and cost optimizations of the structure alternatives were performed. A series of MINLP optimizations were executed over a wide range of various design parameters: different material unit prices, hourly labour costs, imposed loads, structure spans, steel and concrete grades, welded and standard steel sections, plastic and elastic cross-sectional resistances, different positions of the neutral axis and different locations of the centre of gravity axis of the transformed (all steel) section.

The Modified Outer-Approximation/Equality-Relaxation (OA/ER) algorithm was applied. The minimal self-manufacturing costs of the structure, steel and concrete grades and standard sizes were obtained through each individual MINLP optimization. All the results were analysed and compared. Comparative diagrams and a recommended design for a composite floor system were determined. In addition, this study answered some questions regarding the influence of unit prices on the optimal design, the most suitable position of the neutral axis, the competitive spans of the structures with welded and standard steel sections, the competitiveness of the plastic cross-section resistance when compared to the elastic resistance, the spans and loads where the ultimate and the serviceability limit states are predominant and the adequate location of the centre of gravity axis of the transformed (all steel) section.

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1. Introduction

The paper presents a comparative study of design, resistance and economical properties of a composite floor system, composed from a concrete slab and steel I sections, see Fig. 1. Since the considered composite structure is designed from two different materials, the structure's cost optimization was selected here rather than the calculation of weights. A series of mixed-integer non-linear programming (MINLP) optimizations was performed in order to achieve the optimal structure design for a wide range of design parameters e.g. spans and loads. Hence, the multi-parametric MINLP optimization of the composite structure is reported in the study.


The multi-parametric optimization of composite structures has rarely been presented in the literature. The before mentioned Senouci’s and Al-Ansari’s work [4] presented a parametric study of composite beams based on the genetic algorithm. The parametric optimization was executed for three different couples of dead and live loads (the live load up to 16.33 kN/m²) and four various beam spans (up to 10 m). The American wide flange sections were used. Kaveh and Ahangaran [9] introduced a parametric study of composite floor system using the social harmony search model for different couples of dead and live loads (the live load up to...
imposed loads (up to 10 kN/m²) were studied together with the levels of economy. The influences of five different vertical variable couples of material unit prices and hourly labour costs were investigated, different types of design and resistance of the composite cross-section.

A wide multitude of different parameters was defined. The MINLP optimization of the composite structure was performed and studied for parameters that would have an influence on the amount of the structure costs, such as material unit prices for manufacturing, hourly labour costs, load on the structure, structure span, and the cheaper steel plates and channel sections, and different hourly labour costs. The plastic bending resistance was considered.

While the parametric NLP optimization in Refs. [10–12] gave the continuous optimal parameters (dimensions and material grades) only, the present paper discusses a discrete multi-parametric MINLP optimization in order to gain real optimal designs with discrete standard sizes and material grades. For this purpose, the competitiveness of the optimal composite floors with welded steel I sections and the composite structures with steel trusses show their advantages. The multi-parametric optimization was performed for the combinations between different composite designs, various imposed loads (up to 20 kN/m²), different spans (up to 50 m), steel grades, concrete strengths, prices of structural steel, steel price ratios of the more expensive steel hollow sections and the cheaper steel plates and channel sections, and different hourly labour costs. The plastic bending resistance was considered.

When the influences of the material prices and the hourly labour costs on the structure costs were investigated, different couples of material unit prices and hourly labour costs were considered during the study regarding the world’s different income levels of economy. The influences of five different vertical variable imposed loads (up to 10 kN/m²) were studied together with the self-weight of the structure. Ten different structure spans were considered (up to 50 m). When the design and resistance of the composite cross-section was examined, different design possibilities were studied such as different grades of structure steel, different concrete strengths, different types of steel sections (welded and standard steel IPE and HEA sections), different types of the composite cross-sectional resistances (plastic or elastic resistances), different positions of the neutral axis for bending resistance, as well as different positions of the centre of gravity axis of the transformed (all steel) section for the calculations of deflections. In addition, different discrete alternatives of steel wire meshes for reinforcing the concrete and various discrete alternatives for rounding the depth of the concrete slab by a whole cm were also considered, increasing the combinatorics of the proposed discrete optimization problem in the study.

The composite steel-concrete superstructure was generated and different MINLP optimization models were developed for different design possibilities (the plastic and elastic resistances, etc.). The accurate cost objective function was subjected to the set of equality and inequality constraints known from the structural analysis and dimensioning. These constraints were determined in accordance with Eurocode 4 [13]. Since this MINLP problem was discrete, comprehensive, non-linear and non-convex, the Modified Outer-Approximation/Equality-Relaxation (OA/ER) algorithm was applied to perform the optimization, see Kravanja and Grossmann [14] and Kravanja et al. [15]. A number of individual MINLP optimizations were performed for combinations amongst the above mentioned design parameters. All the results obtained from the individual MINLP optimizations were compared and analysed. Comparative diagrams were developed. By the presented multi-parametric MINLP optimization we wanted not only to obtain the optimal structure design for the defined parameters but also to find answers on the following six questions:

1. What are the influences of different material unit prices and hourly labour costs on the optimal composite design and its dimensions?
2. Which position of the composite cross-sectional neutral axis provides the more competitive composite design?
3. How much is the composite design based on the plastic cross-sectional resistance more competitive than the design with the elastic resistance?
4. For which spans do the composite structures with the standard steel I sections represent a more competitive design when compared to those with the welded steel I sections?
5. For which spans are the conditions of the ultimate limit state decisive for the dimensioning and for which spans are the conditions of the serviceability limit state dominant?
6. What is the adequate location of the centre of gravity axis of the transformed (all steel) section?

Finally, a recommended optimal design, presented at the end of the paper, was determined for a composite I beam floor system for choosing the optimal type of structure.

2. MINLP problem formulation

As the optimization problem of the composite floor system is discrete, non-convex and non-linear, the mixed-integer non-linear programming (MINLP) is selected for application. The non-convex, non-linear and combined discrete-continuous optimization problem can be formulated as a general MINLP problem in the following form:

![Fig. 1. Composite floor system.](image-url)
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