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Influence of genetic algorithm parameters on the structural optimization of open web steel beams

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Abstract. Structural optimization has emerged as an essential tool in engineering, driven by the growing demand for more conscious and efficient use of resources. This context supports the adoption of computational optimization techniques in civil construction projects, especially in the development of lighter structural elements with improved mechanical performance. Silva and Lübke[1] applied the finite element software FEMOOP, developed in C++, for the modeling and analysis of steel open web beams. The software includes the formulation of a three-node triangular finite element under plane stress conditions, along with specific routines for shape optimization and the detailing of the ideal cutting line based on the obtained model. The present study aims to evaluate the influence of varying parameters used in genetic algorithms on the results produced by the implemented optimization routine. Different parameter combinations—such as initial population size, crossover rate, mutation rate, and elitism—were tested and applied to the optimization of different open web beams. The results indicate that proper calibration of these parameters can significantly affect the algorithm's performance and the quality of the solutions generated, directly impacting the load-bearing capacity of the optimized beams. Thus, this study contributes to the advancement of the structural optimization process, providing guidance for selecting more efficient configurations when applying genetic algorithms to the design of web open steel beams.

Keywords: hollow core beams, optimization, finite elements.

1 Introduction

Open web steel beams represent a modern structural system widely applied in building projects, standing out for their ability to combine structural efficiency with material rationalization. The geometry resulting from the profile expansion process provides a significant increase in inertia and flexural strength without a proportional increase in mass. This feature enables the execution of longer spans, reduction of self-weight, and consequent steel savings. In addition, the open-web configuration facilitates the integration of building services, as it allows for the passage of ducts and installations, thereby offering greater flexibility to architectural design and infrastructure solutions.

In this context, several studies have investigated different aspects related to the structural behavior of web open beams, addressing both analytical and numerical approaches. Research conducted by Alves and Lubke [2], Dias [3], Sonck and Belis [4], Silveira [5], Chung [6], Veríssimo [7], Bezerra [8], Abreu [9], and Faria [10] contributed to the advancement of knowledge on the design and verification of such structures under limit states. More recently, Silva and Lübke [1] developed an optimization program for steel web open beams using the finite element method combined with genetic algorithms, presenting the formulation employed, its validation, and illustrative numerical applications.

The present study builds upon this line of research by evaluating the influence of genetic algorithm

parameters on the optimization process of steel web open beams. The objective is to understand how adjustments in algorithm configuration affect the quality and efficiency of the structural solutions obtained, thus providing support for faster, more robust, and more accurate analyses. In this way, this research aims to contribute to the improvement of computational tools applied to the design of steel structures, enhancing the applicability of web open beams in contemporary construction systems.

2 Formulation of the optimization problem

Silva and Lubke [1] developed an optimization program in C++ using genetic algorithms and the finite element method. The program's objective is to determine the shear line that maximizes the load capacity of the open web steel beam. The design variables are parameters that define the dimensions and position of the shear lines that form the open web steel beam. Each design variable has geometric constraints related to the profile shape, in order to obtain shear lines with possible practical application. The geometric constraints will configure the lateral constraints, and behavioral constraints are also defined to address stress and deformation limitations.

In the study by Silva and Lubke [1], constraints related to out-of-plane displacement of the element are not considered in the formulation. Analytical formulations based on the studies presented by Abreu[9] and Bezerra[8] are used to evaluate lateral torsional buckling (LTB) and web buckling (WPB).

The formulation of the optimization program, including details regarding the finite element program used and the implemented optimization program are presented in detail in Lubke [11]. A flowchart of the program developed by Silva and Lubke [1] is shown in Figure 1.

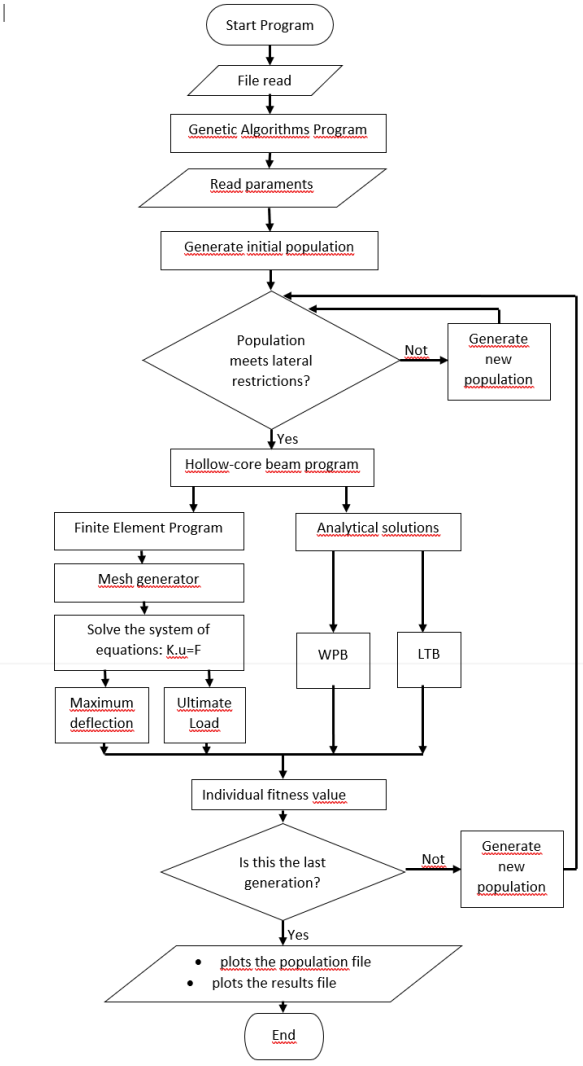


Figure 1. Flowchart of the developed program (Source: Silva and Lubke [1])

An input file is generated by the user, providing as input data the maximum number of generations to be considered, mutation and crossover rates, parameters related to the material used, characteristics of the beam to be analyzed, such as dimensions and support conditions, as well as the geometry of the original profile. For the finite element routine, the parameters determined by the user, through the input file, are the shape of the honeycomb (hexagonal or elliptical) and the respective minimum and maximum limits for the design variables.

For the purposes of this study, a web open beam was optimized through the variation of optimization parameters. The structural model considered consists of a simply supported beam with a 10-meter span, subjected to a uniformly distributed load. In the development of this example, the cross-sectional dimensions of a doubly symmetric I-shaped section, fabricated from ASTM A572 Gr. 50 steel, were adopted. The corresponding beam geometry is presented in Figure 2. This same example is analyzed by Lubke[11], with different configurations being tested for the optimization parameters.

$d = 506{,}1\ mm$
$b_f = 287{,}3\ mm$
$t_f = 12{,}6\ mm$
$t_w = 8{,}1\ mm$
$r = 0\ mm$

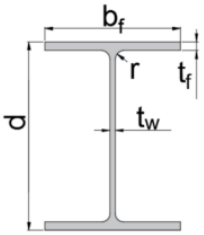


Figure 2. cross-section geometry (Source: Lubke [11])

For the web open optimization problem, three design variables were considered, as illustrated in Figure 3, each encoded with 10 bits in binary representation. The limits adopted were 0.05 m to 0.30 m for a_o, 0.10 m to 0.70 m for b_o, and 0.10 m to 0.4335 m for h_o. The cutting position was defined to ensure that the openings were symmetrical with respect to the beam height.

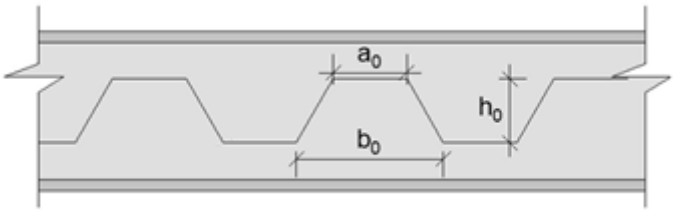


Figure 3. Design variables (Source: Lubke[11])

3 Analysis of results

To evaluate the influence of the parameters used in the genetic algorithm program, the example presented in this section was subjected to optimization processes, varying the population size, the number of generations, the crossover rate, and the mutation rate. This analysis aimed to verify the adequacy of the parameters used, seeking to avoid both configurations that result in high computational costs and those that could lead to local minimum solutions.

Populations with crossover rates of 80% and 90% and mutation rates of 1%, 2%, 3%, and 5% were analyzed. The population sizes evaluated were 10, 20, 30, and 50 individuals. Each of the combinations was analyzed 5 times and the difference between the results found was less than 1% for the limit load. The results for some of the combinations of the variables tested are presented in Table 1.

Table 1. Coefficients in constitutive relations

Optimization Parameters					Limit Load			
Crossover Rate	Mutation Rate	Population Size	Generation Limit	Convergence Generation	ULS (kN)	SLS (kN)	WPB (kN)	LTB (kN)
80%	3%	10	100	72	89.2	86.0	36.7	36.1
80%	2%	10	100	50	90.0	86.8	36.4	36.3
80%	1%	10	100	76	89.9	86.1	36.2	36.2
80%	3%	20	100	58	90.5	86.4	36.2	36.2
80%	2%	20	100	71	91.1	86.4	36.4	36.2
80%	1%	20	100	86	91.4	86.5	36.5	36.2
80%	3%	30	70	53	89.1	86.2	36.6	36.2
80%	2%	30	70	67	88.8	86.7	36.2	36.3
80%	1%	30	70	80	88.9	86.6	36.2	36.2
80%	3%	50	100	63	91.0	86.4	36.4	36.2
90%	5%	10	100	61	90.3	86.4	36.2	36.2
90%	3%	10	100	41	90.9	86.7	36.4	36.3
90%	2%	10	100	72	87.8	86.5	36.4	36.2
90%	1%	10	100	77	82.8	82.8	36.5	36.1
90%	3%	20	100	58	90.8	86.4	36.4	36.3
90%	2%	20	100	77	90.8	86.8	36.4	36.4
90%	1%	20	100	86	87.4	86.1	36.5	36.2
90%	3%	30	70	42	91.1	86.7	36.5	36.3
90%	2%	30	70	64	90.0	86.3	36.4	36.2
90%	1%	30	70	63	87.7	86.4	36.3	36.2

The tests performed indicate that the mutation rate significantly impacts the solution's convergence speed. A mutation rate of 3% yielded the best results for the example analyzed. Lower mutation rates tend to increase the number of generations required for convergence and the likelihood of the analyzed solution reaching a local minimum. Higher mutation rates may delay convergence due to the greater likelihood of the best individuals mutating. The highest crossover rate, 90%, yielded the fastest convergence. It was observed that decreasing the crossover rate increases the number of generations required for convergence.

Population size significantly impacts the time required for analysis. A population of 20 individuals performed best, yielding results more consistent with an average analysis time. Populations of 30 and 50 individuals require much longer analysis time, with no direct gain in convergence speed. Populations of 10 individuals present a significantly shorter analysis time; however, in some analyses, rapid convergence to local minima was observed, not approaching the optimal solution.

A quantitative analysis of the results indicates that the ultimate load converged to approximately 36.2 kN/m, with noticeable differences in the results for the ULS, although all with values between 81 kN/m and 91 kN/m. Regarding the shape of the opening considered, for the example analyzed, it is noted that the optimized beam presents an expansion ratio of approximately 1.62 for all tests performed. The width of the upright (a_0) varied between 5.2 and 7.4 centimeters, representing 6% to 9% of the height of the alveolar beam obtained. The width of the alveoli (b_0) found varied between 58.6 and 69.9 cm, representing 73% to 87% of the height of the alveolar profile.

After the analyses carried out, it is suggested to use populations of 20 individuals, with a mutation rate of 3% and a crossover rate of 90% for the optimization of steel hollow core beams in the program developed by Silva and Lubke[1].

Since analytical formulations are used to determine the WPB and LTB, the program tends to converge quickly to results that approach the limits established by the analytical formulation, increasing the algorithm's success rate.

However, further investigation is required, with the implementation of a finite element suitable for evaluating out-of-plane deformations. This eliminates dependence on analytical formulations and allows the genetic algorithm to obtain more diverse results.

4 Conclusions

The present study investigated the influence of parameter selection on the optimization of steel cellular beams. The findings indicate that the appropriate choice of genetic algorithm parameters—particularly population size, crossover rate, and mutation rate—exerts a decisive impact on both solution quality and computational efficiency. Results further revealed that intermediate parameter settings promote convergence toward more stable and effective solutions, mitigating the risks of local minimum and excessive computational demands. Based on these outcomes, recommendations for parameter configurations to be employed in future optimization studies are provided.

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