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About some important changes in applied structural optimization

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Summary

Structural optimization is special domain of employment researching many and how different problems in the field of forming structure. In times of early computer science and computational technology, when the access to "computing time" of the machine was strongly regulated (from the point of view of considerable costs) some optimization problems were very strongly simplified, so their solution could be possible without mathematical programming methods and therefore cheaper.

In times of stormy development of informatization and almost free-for-all personal computers as well as specialized software, complication of structural optimization modeling has grown considerably.

In this paper being short recapitulation of achievements made by Division of Computational Methods in Engineering Design, it refers to these earliest problems and to these very modern both dealing with applied structural optimization, what is the domain of interest of our team from over 25 years.

KEYWORDS: structural optimization, scalar optimization problem, genetic algorithm, vector optimization problem

1. INTRODUCTION

As member of the Team for Computational Methods in Engineering and Design, I have started dealing with the applied structural optimization in the end of 70-ties in XX century. In the beginning it was research concerning steel bar structures (trusses and frames) and industrial buildings (concrete beams, silos and tanks). All of these early problems mentioned above were formulated and then solved as scalar optimization questions.

Next we started researching with vector optimization problems (steel frames and trusses) and genetic algorithms (thanks to cooperation with Carlos Coello Coello and Gregorio Toscano-Pulido).

In this paper I'm trying to bring you closer how deep were the differences between these first and last problems (exactly in this year was my personal 25th anniversary of optimization research).

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2. SCALAR OPTIMIZATION PROBLEM

2.1. Simple example of the tank welded from steel

The first example of optimization I want to present (in this case example of scalar optimization, started and conducted in 1981) is a tank (the part of steel water tower), shown on the drawing below (Figure 1).

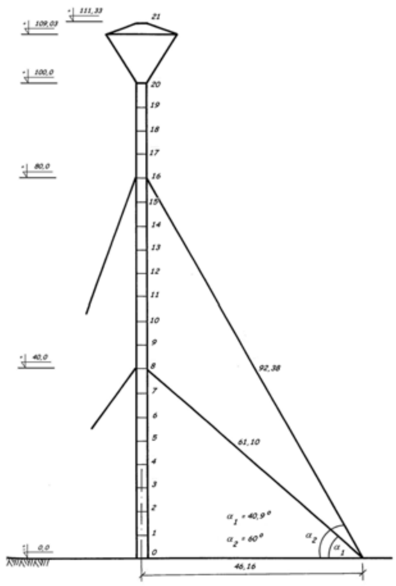

Figure 1. Steel water tower

For optimization the following lump of the tank, made from two cut off cones and one internal cylinder, has been chosen. Surface plan it in places of intersections circled wreaths stiffening. Described has resulted from capacity form highly, allocations and easy installment available methods (so called "easy" or "heavy" one).

2.2 Scalar optimization model

As criterion of optimization accept minimum of expenditure of material preliminary. Become setting up average thickness of covering above-mentioned question fetch for determination of condition of occurrence of minimum of lateral surface. Besides, it accepts following foundation and simplification:

- dimension section - they mirror middle surface,
- thickness of covering is constant (and average),

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- water fulfills only maximum bottom cone,
- we use only one design variable: corner of inclination of surface for vertical α in bottom cone (see Figure 2),
- capacity of useful tank totals 600 m^3.

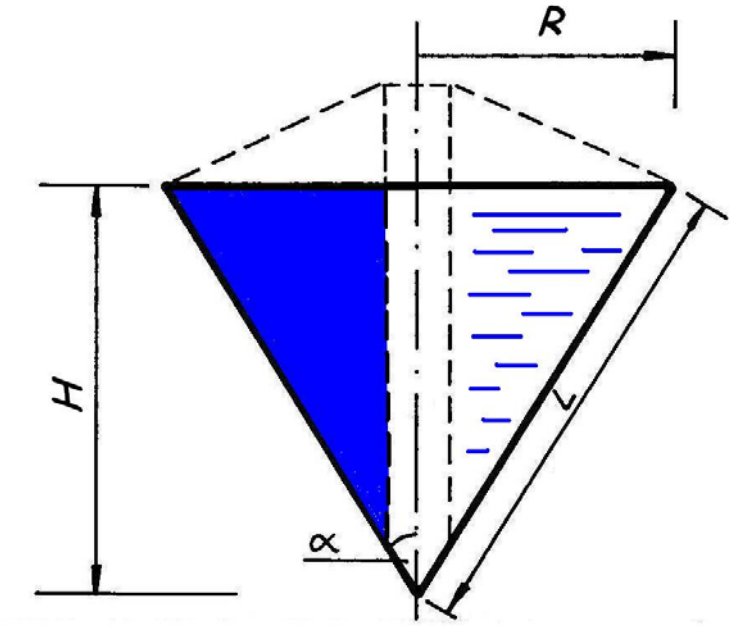

Figure 2. Steel tank – lump and design variable α

It takes into consideration, in the farthest consideration, following geometric dependences:

$$R = H \cdot tg\,(\alpha)\,, \tag{1}$$

$$L = H \,/\, cos\,(\alpha)\,, \tag{2}$$

Field of the lateral surface:

$$F = \pi \cdot R \cdot L = H \cdot tg(\alpha) \cdot H \,/\, cos\,(\alpha) = H^2 \cdot tg(\alpha) \,/\, cos\,(\alpha), \tag{3}$$

Capacity of the cone:

$$V = 600 = 1/3\ \pi \cdot R^2 \cdot H = \ldots = 1/3\ \pi \cdot H^3 \cdot tg^2(\alpha), \tag{4}$$

Basing on (4) in the function of the corner α, next H was indicated:

$$H = [1800 \,/\, \pi \cdot tg2(\alpha)]^{1/3}\ , \tag{5}$$

and it put for (1)

$$F = A \bullet \sin^{-1}(\alpha) \bullet [tg^2(\alpha)]^{1/3} ,$$

$$\text{where } A = 1800 \bullet (\pi/1800)^{1/3} = \ldots = 216{,}72 , \qquad (6)$$

Task of minimization solve existence of minimum of function alternate one researching F(α).

$$\min F(\alpha) \leftrightarrow F'(\alpha) = 0, \qquad (7)$$

Solution illustrate on the drawing (see Figure 3). Next it verify „candidate for minimum" (α') calculating in this point value of second derivative function F''(α):

$$F''(\alpha') = \ldots = 1{,}833 > 0 \qquad (8)$$

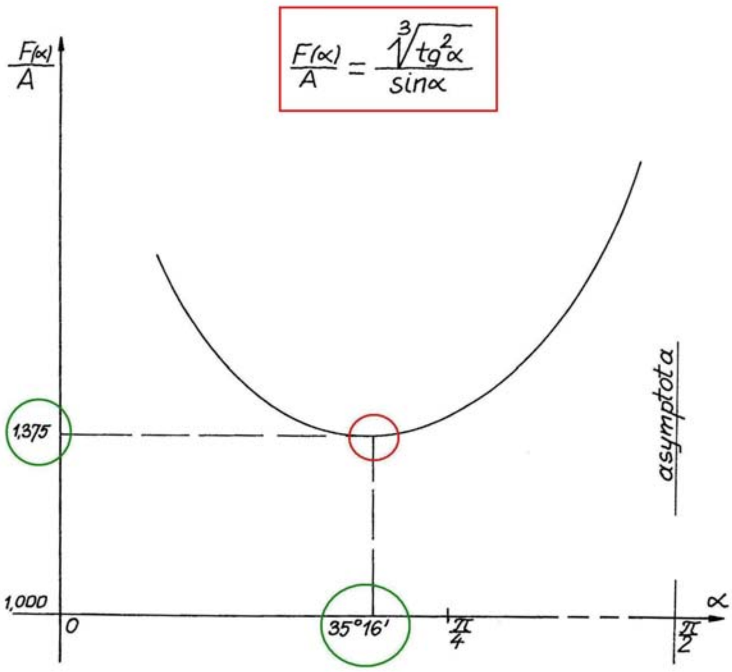

Figure 3. Solution of question of simple scalar optimization

2.3 Recapitulation and final conclusions

It exert in the first approximation, that conical tank has minimal field of lateral surface (but what behind it go, grant demanded criterion: minimum of material), when it lateral is drooping for vertical under corner creating α = 35° 16''.

Having the corner of creating inclination α and foundations or simplifications mentioned on admission of preamble, remained dimension of the tank have been calculated from simple geometric dependences.

Fundamental geometric dimensions of the tank accepted for the farthest technical and executive design, it present on following drawing (Figure 4).

Assuring, as contact limit, the smallest surface of conical covering with aggressive environment (the water stored in this tank, so-called: industrial, with mineral small parts inclusive, about predefined temperature gone up with technological respects) we can prominently extend the constancy of maintenance of the building (water tower) in the best condition.

3. MICRO-GA AS AN EFFECTIVE SOLVER FOR MULTIOBJECTIVE OPTIMIZATION PROBLEMS

3.1. Genetic algorithms in multiobjective structural optimization

Genetic algorithms (GAs) have become very popular optimization techniques in structural optimization, but their use in multiobjective structural optimization has become less common. Additionally, only few researchers have emphasized the importance of efficiency when dealing with multiobjective optimization problems, despite the fact that its (potentially high) computational cost may become prohibitive in real-world applications.

In this paper, we present a GA with a very small population size and a reinitialization process (a micro-GA) [1] which is used for multiobjective optimization of trusses.

3.2. The micro-GA

This micro-GA approach elaborated by Toscano-Pulido [3,5] works as follows (Figure 5). It starts with a random population, it uses two memories: a replaceable (that will change during the evolutionary process) and a non-replaceable (that will not change) portion. Micro-GA uses 3 types of elitism.

The first is based on the notion that if we store the non-dominated vectors produced from each cycle of the micro-GA, we will not lose any valuable information obtained from the evolutionary process.

The second is based on the idea that if we replace the population memory by the nominal solutions (i.e., the best solutions found when nominal convergence is reached), it will gradually converge, since crossover and mutation will have a higher probability of reaching the true Pareto front of the problem over time. The third type of elitism is applied at certain intervals (defined by a parameter called "replacement cycle"). It takes a certain number of points from all the regions of the Pareto front generated so far and it uses them to fill the replaceable memory. Depending on the size of the replaceable memory, it chooses as many points from the Pareto front as necessary to guarantee a uniform distribution.

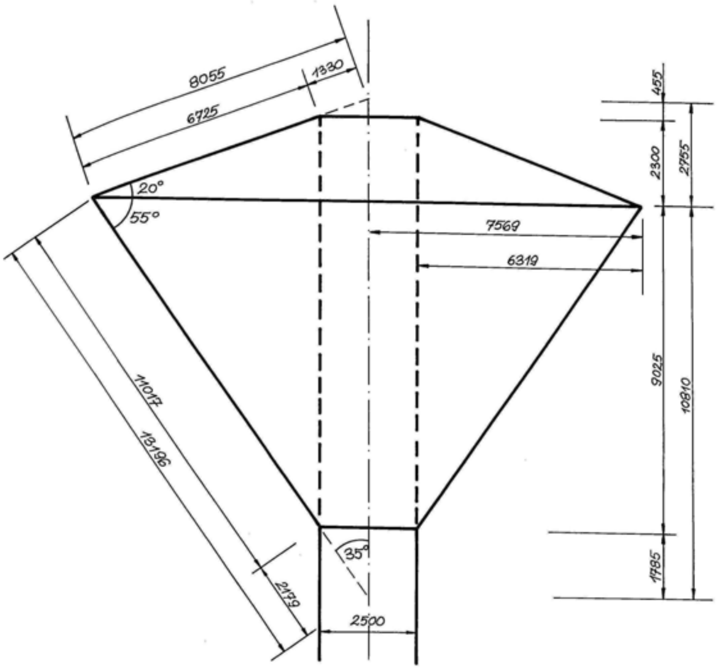

Figure 4. Conical tank accepted for the farthest technical design

This process allows us to use the best solutions generated so far as the starting point for the micro-GA, so that we can improve them (either by getting closer to the true Pareto front or by getting a better distribution along it). To keep diversity in the Pareto front, it uses an approach based on geographical location of individuals (in objective function space) similar to the adaptive grid proposed by Knowles & Corne [2]. This approach is used to decide which individuals will be stored in the external memory once it is full. Individuals in less populated regions of objective space will be preferred.

In previous work, our micro-GA has performed well (in terms of distribution along the Pareto front, and speed of convergence to the global Pareto front) with respect to other recent evolutionary multiobjective (vector) optimization approaches, while requiring a lower computational cost [3].

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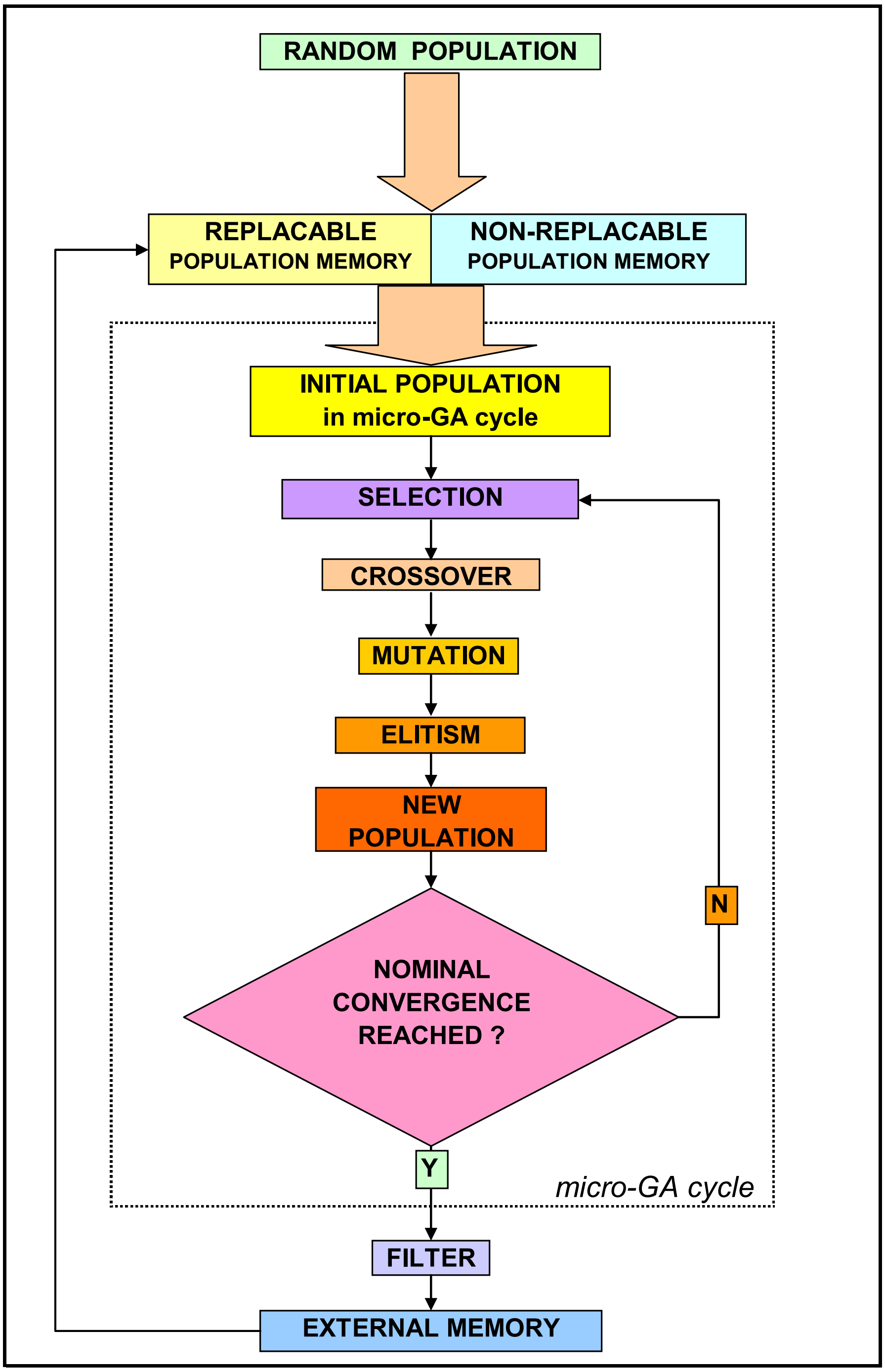

Figure 5 : Diagram of micro-GA

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3.3. Illustrative example

The 4-bar plane truss shown in below (Figure 6) is used to illustrate this approach. Two objectives were considered in this case: minimize volume and minimize its joint displacement δ. Four decision variables are considered (for details of this problem, see [4]).

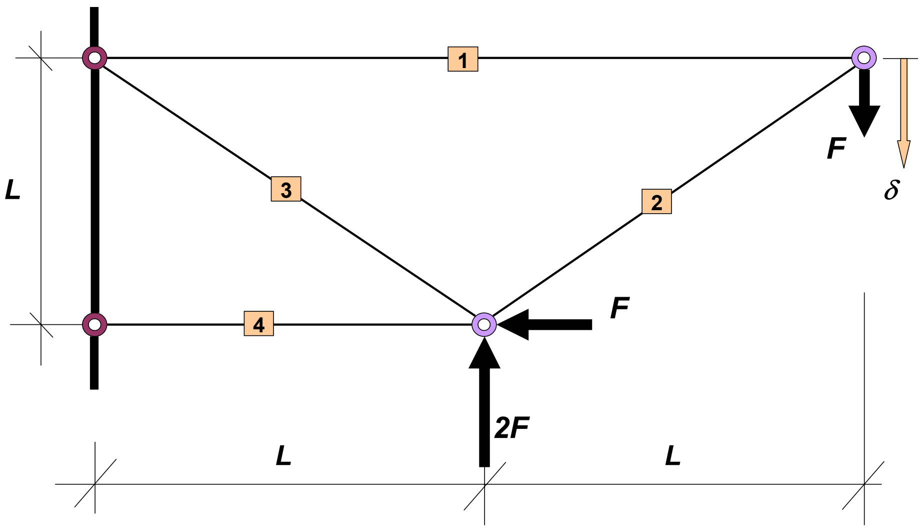

Figure 6 : Four-bar plane truss with one loading case

The Pareto front produced by micro-GA mentioned above, and its comparison against the global Pareto front (produced using an enumerative approach) is shown in the next figure (Figure 7).

3. CONCLUSIONS

The task of structural optimization is to support the constructor in searching for the best possible design alternatives of specific structures. The "best possible" or in the other words "optimal" structure means that structure which mostly corresponds to the designer's objectives meeting of operational, manufacturing and application demands simultaneously.

Compared with the "trial and error"- method mostly used in engineering practice (and based on an individual, intuitive, empirical approach) the seeking of optimal solutions by applying MOP (mathematical optimization procedures) is much more efficient and reliable. Nowadays in the time of market economy also research has

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to be "market one". In my opinion "to be market" is now the greatest challenge for applied optimization in Poland and everywhere [6].

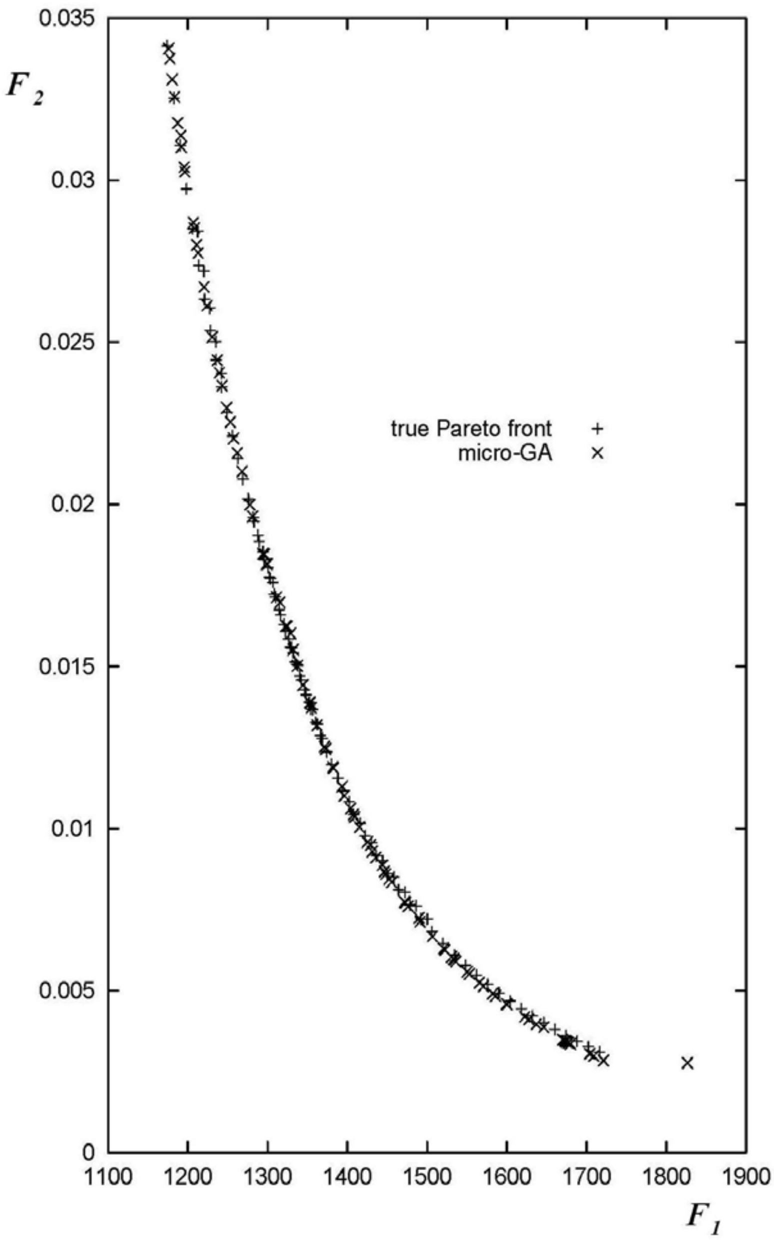

Figure 7. True Pareto front vs. front obtained by micro-GA

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