VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Darius MAČIŪNAS

MULTI-OBJECTIVE GLOBAL OPTIMIZATION OF GRILLAGES USING GENETIC ALGORITHMS

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
MECHANICAL ENGINEERING (09T)

Vilnius LEIDYKLA TECHNIKA 2013

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2009–2013.

Scientific Supervisor

Prof Dr Habil Rimantas BELEVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T).

The dissertation is being defended at the Council of Scientific Field of Mechanical Engineering at Vilnius Gediminas Technical University:

Chairman

Prof Dr Habil Rimantas KAČIANAUSKAS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T).

Members:

Prof Dr Habil Juozas ATKOČIŪNAS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T),

Prof Dr Habil Gintautas DZEMYDA (Vilnius University, Technological Sciences, Informatics Engineering – 07T),

Assoc Prof Dr Rimvydas GAIDYS (Kaunas University of Technology, Technological Sciences, Mechanical Engineering – 09T),

Prof Dr Julius ŽILINSKAS (Vilnius University, Technological Sciences, Informatics Engineering – 07T).

Opponents:

Prof Dr Habil Rimantas BARAUSKAS (Kaunas University of Technology, Technological Sciences, Mechanical Engineering – 09T),

Prof Dr Vytautas TURLA (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T).

The dissertation will be defended at the public meeting of the Council of Scientific Field of Mechanical Engineering in the Senate Hall of Vilnius Gediminas Technical University at 2 p. m. on 6 June 2013.

Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.
Tel.: +370 5 274 4952, +370 5 274 4956; fax +370 5 270 0112;
e-mail: doktor@vgtu.lt

The summary of the doctoral dissertation was distributed on 3 May 2013.
A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Darius MAČIŪNAS

DAUGIAKRITERIS GLOBALUS SIJYNŲ OPTIMIZAVIMAS GENETINIAIS ALGORITMAIS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
MECHANIKOS INŽINERIJA (09T)

VGTU
LEIDYKLA
Vilnius TECHNIKA 2013

Disertacija rengta 2009–2013 metais Vilniaus Gedimino technikos universitete.
Mokslinis vadovas

prof. habil. dr. Rimantas BELEVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Disertacija ginama Vilniaus Gedimino technikos universiteto Mechanikos inžinerijos mokslo krypties taryboje:

Pirmininkas

prof. habil. dr. Rimantas KAČIANAUSKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Nariai:

prof. habil. dr. Juozas ATKOČIŪNAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. habil. dr. Gintautas DZEMYDA (Vilniaus universitetas, technologijos mokslai, informatikos inžinerija – 07T),

doc. dr. Rimvydas GAIDYS (Kauno technologijos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. dr. Julius ŽILINSKAS (Vilniaus universitetas, technologijos mokslai, informatikos inžinerija – 07T).

Oponentai:

prof. habil. dr. Rimantas BARAUSKAS (Kauno technologijos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. dr. Vytautas TURLA (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Disertacija bus ginama viešame Mechanikos inžinerijos mokslo krypties tarybos posėdyje 2013 m. birželio 6 d. 14 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.
Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.
Tel.: (8 5) 274 4952, (8 5) 274 4956; faksas (8 5) 270 0112;
el. paštas doktor@vgtu.lt

Disertacijos santrauka išsiuntinėta 2013 m. gegužės 3 d.
Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).
VGTU leidyklos „Technika“ 2122-M mokslo literatūros knyga.

Introduction

Formulation of the problem and topicality of the work. The ability to design the rational structure in short terms is obvious economical demand hence the engineer must have at his disposal the methodology of optimization of such structures. Grillage structures are widely used in engineering practice, e. g. in construction of so-called grillage-type foundations (*further* grillages). Nowadays the good-performing optimization algorithms for topology optimization of grillages – separately investigating each beam in the grillage – are elaborated therefore the main attention of this work is devoted to the simultaneous topology and size optimization of grillages, which is obviously insufficiently explored so far.

The optimal grillage should meet twofold criteria: the number of piles should be minimal, and the connecting beams should receive minimal feasible bending moments what leads to minimal consumption of concrete for beams. Obviously two separate optimization problems are considered here: determination of minimal number of piles and determination of minimal volume of beams. Whereas the carrying capacity of a single pile is known, the first optimization problem can be rendered as minimization of the maximal reactive force in piles among all set of piles. Analogously, the second problem corresponds to the minimization of the maximal bending moments in connecting beams. The bending moments depend also on stiffness of beams hence the cross-sectional dimensions of beams must be identified simultaneously. Both problems can be incorporated into one applying a compromise objective function. The results of optimization are the number of required piles and their placement scheme, and the cross-sectional dimensions of connecting beams. The minimal possible number of piles is determined by dividing all active forces (applied on a grillage) by carrying capacity of a single pile. An even distribution of reactive forces among all set of piles and even distribution of bending moments in connecting beams indicates an ideal grillage. Practically it is hardly possible, especially in case when a designer introduces the so-called "immovable supports" (usually at the corners of grillages) which cannot change their position and are not involved into optimization process. Such supports could hinder to achieve global solution hence the immovable supports are not considered in the present work and piles are allowed to take whatever position in the grillage. Therefore the objective functions are very sensitive to the placement of piles: even a small shift of one pile could lead to a significant change of value of the objective function. In mathematical terms, it is a highly non-convex, global optimization problem.

Object of research. Mechanical structure of grillages. The grillages are composed of supporting piles and connecting beams. Optimization of mechanical properties (reactive forces in piles and bending moments in beams) of grillages is investigated and realized.

Aim and tasks of the work. The main objective of the present work is to create a technology enabling to perform simultaneous topology and size optimization of grillages of relevant for the engineering practice size employing the concept of genetic algorithms (GA).

The following tasks have to be performed:

1. Review the scientific literature about the main methods for global and multi-objective optimization of grillages.
2. Create the calculation technology for separate topology and size optimization of grillages using GA.
3. Create the calculation technology for simultaneous topology and size optimization of grillages using GA.
4. Create the calculation technology for simultaneous topology and size optimization of grillages using adaptive genetic algorithm (AGA).
5. Create the calculation technology for simultaneous topology and size optimization of grillages using genetic algorithm with distribution strategy (GADS).

Methodology of research. The computational solution methods are employed in the present work. Compromise objective function, containing the maximal reactive force in piles and the maximal in absolute value bending moment in connecting beams, to be minimized is subjected to the constraints of static equilibrium, maximum allowed reactive force in a pile, maximum allowed in absolute value bending moment in connecting beam, boundary conditions to cross-sectional dimensions of beams and boundary conditions to positions of piles. The magnitude of the objective function is evaluated as well as the control of constraints is performed using the finite element method. The genetic algorithms are employed for the optimization. All the software is created by author of the present work. The solution results were tested and verified using finite element package ANSYS.

Scientific novelty

1. The original technology for simultaneous topology and size optimization of grillages has been suggested and implemented in original software package; the GA has been suggested and investigated for these purposes.

2. The original technology for simultaneous topology and size optimization of grillages has been suggested and implemented in original software package; the adaptive GA (AGA) has been suggested and investigated for these purposes; this algorithm has yielded on average 3% better (i. e. lower) values of the objective function than the classical GA.
3. The original technology for simultaneous topology and size optimization of grillages has been suggested and implemented in original software package; the GA with distribution strategy (GADS) has been suggested and investigated for these purposes; this algorithm has yielded on average 5% better (i. e. lower) values of the objective function than the classical GA.

Practical value. The suggested calculation technologies can be used for optimization of grillages of relevant for the engineering practice size. Applying GA, typically several rational solutions may be obtained. These solutions have close values, but different schemes of grillages. This can be useful in engineering practice, because a designer can choose the acceptable, in his opinion, scheme of a grillage.

Defended propositions

1. The suggested technology of simultaneous topology and size optimization of grillages applying adaptive GA (AGA) exhibits on average 3% better solutions of the objective function than the classical GA.
2. The suggested technology of simultaneous topology and size optimization of grillages applying GA with distribution strategy (GADS) exhibits on average 5% better solutions of the objective function than the classical GA.

Approval of the work results. On the topic of dissertation there were 7 papers published in scientific journals. The results were presented at 8 scientific conferences, of which 3 – international.

The scope of the scientific work. The dissertation is presented in Lithuanian language. It consists of five parts including introduction, 3 chapters, general conclusions, references and 3 annexes. The dissertation comprises 120 pages including annexes, 16 tables and 50 illustrations. The list of references comprises 186 items.

1. Review of methods for global multi-objective optimization of grillages

In this chapter the main global and multi-objective optimization methods used in engineering practice for optimization of grillages are described. Also the historical review of optimization of grillages and the main traits of state-of-the-art research in this field are surveyed. Usually, the global optimization problems require huge computer resources therefore the stochastic (probabilistic) global optimization methods seem to be promising. The main attention is given to the genetic algorithms, which simulate the evolution laws of nature.

Engineers employ the GA for optimization of grillages for more than 20 years. Papers of Hajela *et al*. and Saka in 1998 are among the first works in the field should be mentioned.

Simultaneous price and volume optimization of grillages has been researched by Kim *et al*. in 2009. In 2012 Zhou and Li have analyzed grillages applying triangle finite elements and weight of grillages is optimized applying simultaneous optimization of three factors: bending moments, displacements and material density.

After review of literature it is concluded, the problems of global multi-objective topology and size optimization of grillages of relevant for the engineering practice size are still not solved and the methodology for them has to be developed. Similar problems of practically significant size still are not solved to date due to the large number of design parameters: the typical grillage includes several tens of piles and beams. Thus, the solution time may be very long and, moreover, in case of improper solution technique, even unacceptable for engineering practice. Therefore, it is important to choose appropriate optimization algorithm and effective application technique of this algorithm. Review of papers in the field of topology optimization of grillages revealed the genetic algorithms (GA) may be promising here. In this work the GA were adapted for the topology and size optimization of grillages; these modified GA exhibit better results than the classical GA.

2. Genetic algorithm for topology optimization of grillages

This chapter describes how to apply the GA concept to the topology optimization of grillages. Topology optimization of 10 pile and 15 pile grillages are chosen, because Mockus, Belevičius, Šešok, Kačeniauskas have obtained (in the period of 2008–2010) solutions (which have been chosen as benchmark in the current dissertation) of separate topology optimization of the above mentioned grillages. At the beginning the finite element method technology and software, which obtain all necessary characteristics of grillages (stresses and internal forces in beams of grillages, bending moments in connecting beams, displacements of nodes and etc.), are described. Further formulation of optimization problem is presented. Compromise objective function and constraints of problem are introduced. More further the coding of the grillage using the sequence of real numbers and step-by-step GA procedures for grillage optimization are described. And finally, the solutions of topology optimization of 10 pile grillage and contribution of components of the objective function to optimization problem are demonstrated.

Optimization problem is solved using classical GA, which consists of generation of initial population, selection, crossover and mutation. Analysis of a grillage and solution of direct problem to find reactive forces and bending moments (while monitoring the constraints of the problem) in the grillage are performed using original program based on FEM. The algorithm of such program is described. The program is used as a "black-box" routine to the optimization program and solves the main static equation:

$$[K]^a \{u\}^a = \{F\}^a , \tag{1}$$

here a – the ensemble of elements (not shown further), $[K]$ – stiffness matrix, $\{u\}$ – nodal displacements, $\{F\}$ – active forces. The program defines nodal displacements u and then calculates reactive forces (2) and bending moments (3):

$$R_i \sum_j [K_{ij}] \cdot u_j , \tag{2}$$

$$M = EI_z \kappa , \tag{3}$$

$$\kappa = -\frac{d^2}{dx^2}\left(\sum_i N_i u_i \right), \tag{4}$$

here R_i – reactive force at i-th pile, u_j – displacement of j-th degree of freedom (DOF), M – bending moment at the arbitrary point of a beam, depending on a curvature κ (4) of the beam, E – Young's modulus of a beam, I_z – second moment of inertia of a beam, N_i – the second-order Hermitian interpolation functions, u_i – displacement of i-th DOF of a beam.

Multi-objective global optimization problem is formulated introducing compromise objective function (5), which consists of two objectives (6) and (7) with weighting coefficients w_1 and w_2 respectively:

$$f = \min_{x \in D} f(x) = w_1 \cdot f_1(x) + w_2 \cdot f_2(x), \tag{5}$$

$$f_1(x) = \max_{i=1,\ldots N_a} R_i(x), \tag{6}$$

$$f_2(x) = \max_{i=1,\ldots m \cdot N_b} |M_i(x)|, \tag{7}$$

here $f(x)$ – a nonlinear objective function of continuous variables $f : \Re^n \to \Re$, n – the number of design parameters x (i. e. positions of piles and cross-sectional dimensions of connecting beams), $D \subset \Re^n$ – a feasible region of design parameters, $f_1(x)$ – the maximal vertical reactive force R_i at a pile, $f_2(x)$ – the maximal in absolute value bending moment M_i in connecting beams, N_a – the number of piles, N_b – the number of beams, m – the number of sections in one beam where the bending moments are calculated.

Herein individual is encoded as a string of a sequence of real numbers, i. e. pile location in a one-dimensional pattern and cross-sectional dimensions of a beam.

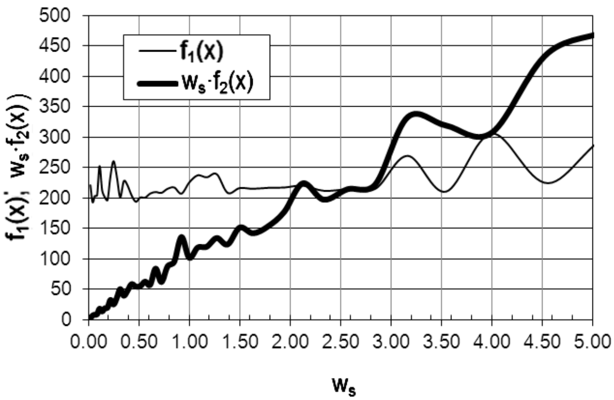

Fig. 1. Contribution of components of the objective function to optimization solution (10 pile grillage)

Topology optimization of 10 pile grillage is performed solving the following tasks: reactive forces minimization ($w_2 = 0$ in (5)), bending moments minimization ($w_1 = 0$ in (5)), bending moments and reactive forces simultaneous minimization ($w_1 = w_2 = 0.5$ in (5)). Herein height h_{sk} and width b_{sk} of cross-section of beams are assumed to be constant.

Analysis of contribution of (6) and (7) to optimization problem (5) revealed (Fig. 1) the value of $w_s = w_2 / w_1$, when (6) and (7) have the equivalent influence to the objective function (5) ($w_s \approx 2.57$ for 10 pile grillage).

3. Genetic algorithm for simultaneous topology and size optimization of grillages

In this chapter the technology for simultaneous topology and size optimization of grillages using GA concept is described and results of optimization of 10 pile and 15 pile grillages are presented. The solution of such problem is usually not a unique optimal objective value, but a set of compromise solutions, called the Pareto-optimal solutions. In the first part of chapter Pareto-optimal solutions and optimal values of GA parameters are introduced. In this work the topology optimization and size optimization will be integrated into one step of algorithm, thus increasing the possibility to obtain the better solution. Contribution of components of the objective function to optimization problem of 10 pile and 15 pile grillages is compared. Solution of optimization problem is performed when (6) and (7) have the equivalent influence to the objective function (5). In the second part of chapter adaptive GA (AGA) and GA with distribution strategy (GADS) are described and optimization problem of 10 pile and 15 pile grillages is solved.

The shape of the objectives $f_1(x) - f_2(x)$ domain has been investigated to verify the convexity of the feasible design space. Fig. 2 and Fig. 3 show the feasible design space in the plane $f_1(x) - f_2(x)$ is convex by the side where the optimal solution is expected. Therefore simple weighting coefficients method (5) is valid and all possible Pareto solutions can be identified.

The results of numerical experiments have revealed close values of $w_s = w_2 / w_1$ for both grillages: (6) and (7) have the equivalent influence to the objective function (5) when $w_s \approx 2.57$ for 10 pile grillage (Fig. 1) and $w_s \approx 2.33$ for 15 pile grillage (Fig. 4).

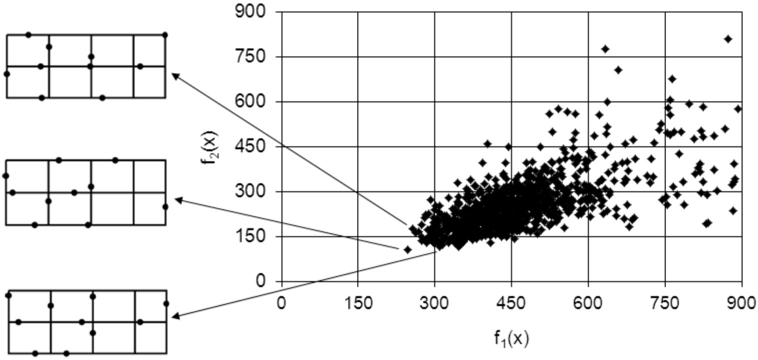

Fig. 2. Possible solutions of the objective function in $f_1(x) - f_2(x)$ space. (10 pile grillage)

.

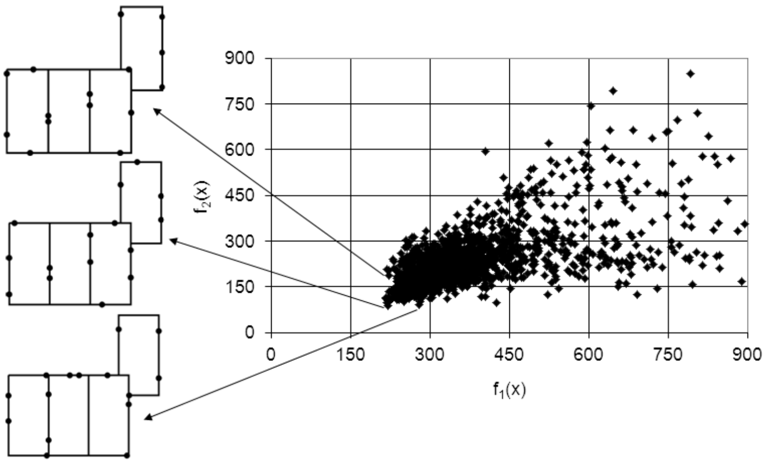

Fig. 3. Possible solutions of the objective function in $f_1(x) - f_2(x)$ space. (15 pile grillage)

The above mentioned $w_s = w_2 / w_1$ values were employed for simultaneous topology and size optimization of grillages:

1. 10 pile grillage: $w_1 = 0.28$, $w_2 = 0.72$ (i. e. $w_s \approx 2.57$).
2. 15 pile grillage: $w_1 = 0.30$, $w_2 = 0.70$ (i. e. $w_s \approx 2.33$).

For beams of grillages the following conditions were applied:

- The range of values for height of cross-section of beam $h_{sk} \in [0.1;0.9]$.
- The range of values for width of cross-section of beam $b_{sk} \in [0.1;0.9]$.
- $(h_{sk} / b_{sk})_{max} \leq 3.0$.

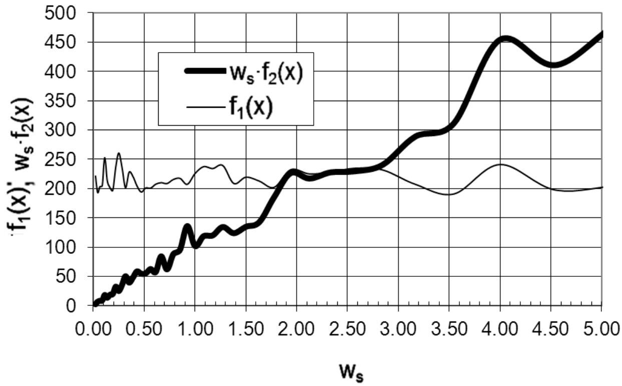

Fig. 4. Contribution of components of the objective function to optimization solution (15 pile grillage)

The pile placement schemes corresponding to the best values of the objective function (5) are shown in Fig. 5.

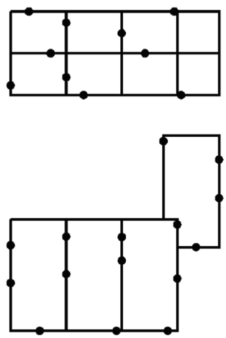

Fig. 5. Pile placement schemes corresponding to the best solution of the objective function (10 pile and 15 pile grillages)

Typical convergence of GA (Fig. 6) clearly indicates fast convergence of the algorithm at the initial phase of the solution and slow convergence after certain number of generations, probably to a local optimal solution.

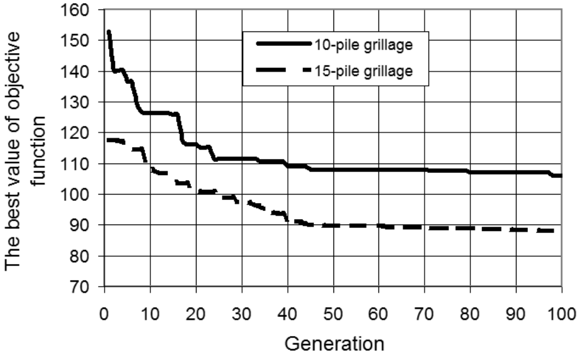

Fig. 6. Typical convergence of GA (10 pile and 15 pile grillages)

Therefore heuristic adaptive GA is suggested. AGA has two main points:

1. The moment of the launching of adaptation is determined by measuring the convergence rate of the best solution in the population, i. e. it is considered the adaptation is required when the gain in the objective function value among 10 generations in a row is less than 5%.
2. The adaptive population size operator *APDO* (8) and the adaptive mutation operator *AMO* (10) are suggested in order to give an impulse to a stalled population to escape from a local solution point. The following constraints (9) and (11) are applied to (8) and (10) respectively:

$$APDO = PD \cdot 0.75\,, \tag{8}$$

$$APDO > 10\,, \tag{9}$$

$$AMO = p\_mut \cdot 1.25\,, \tag{10}$$

$$AMO < 100\,, \tag{11}$$

here PD – size of population, p_mut – mutation probability (%).

The phase of fast convergence of AGA (Fig. 7) lasts approximately two times longer comparing with classical GA (Fig. 6). Though AGA did not yield qualitatively better solutions than GA (approx. 3,01% better for 10 pile grillage and 2,83% better for 15 pile grillage) (Fig. 8), it obviously on average two times saves calculation time, to obtain the same or better results than GA, because faster convergence is stimulated.

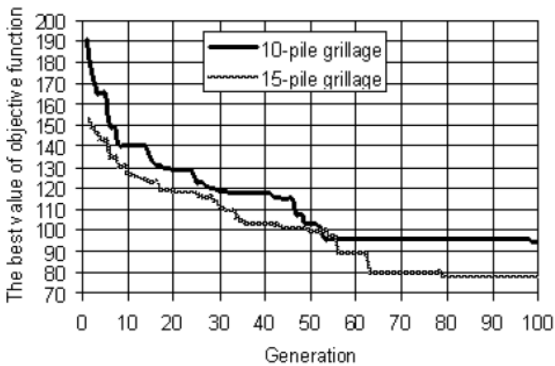

Fig. 7. Typical convergence of AGA (10 pile and 15 pile grillages)

Since calculation time is the crucial factor for all global optimization problems, therefore the suggested AGA is efficient algorithm for optimization of grillages.

While GA usually exhibit slow convergence rate after a particular number of populations, GA with distribution strategy (further GADS) is proposed to improve the performance of GA and achieve better optimization results.

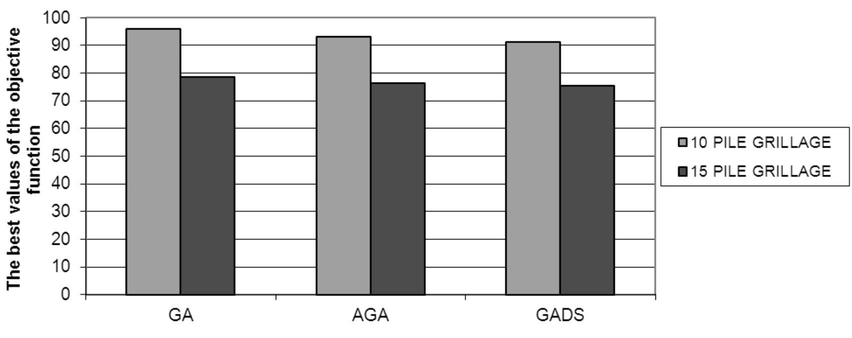

Fig. 8. Comparison of algorithms

Herein optimization with distribution strategy is realized as follows:

1. Three separate optimization routines (classical GA) are launched simultaneously and proceed until the moment, when slowing of convergence prevails. At this particular moment 16 individuals are randomly selected from each of three optimization routines and the new population, composed of 48 selected individuals, is generated.
2. Further optimization is initiated searching for the better solution within the new population. Better optimization results than GA are expected due to the new population, containing individuals, which differ from each other more than individuals within each separate population of three optimization routines. Hence, GADS has a chance to explore a wider area of design space and to obtain better values of the objective function (5) comparing to GA.

The moment of initiation of distribution strategy is identified by estimating the convergence rate of the best solution in the population, i. e. when the gain in the magnitude of the objective function among 10 generations in a row is below 5%. The results (Fig. 8) show GADS has outperformed GA and the best value of the objective function (5) has been improved by 5,12% (10 pile grillage) and 4,25% (15 pile grillage) comparing to GA.

General conclusions

1. It is advantageous to perform multi-objective global optimization of grillages using stochastic algorithms of global optimization, including genetic algorithms, which are one of the most advantageous.
2. Based on the dependence between the values of two criteria of the objective function and the values of ratio of weighting coefficients, it is possible to choose different schemes of grillage, depending on which criteria (reactive force in a pile or bending moment in a beam) have bigger, smaller or the equivalent impact on the solution of the problem. This can be useful in engineering practice, because a designer can choose the acceptable, in his opinion, scheme of a grillage.
3. The developed calculation technology (using GA) is appropriate to solve simultaneous topology and size optimization problem of grillages within reasonable time for engineering practice and all possible Pareto solutions may be identified.
4. The calculation technology for simultaneous topology and size optimization of grillages applying AGA is proposed and realized. AGA has yielded on average 3% better results (i. e. lower values of the objective function) than classical GA. Due to higher rate of

convergence AGA has outperformed GA by on average two times saving calculation time, which is the crucial factor for all global optimization problems.

5. The calculation technology for simultaneous topology and size optimization of grillages applying GADS is proposed and realized. GADS has yielded on average 5% better results (i. e. lower values of the objective function) than classical GA.

List of Published Works on the Topic of the Dissertation
In the reviewed scientific periodical publications

Mockus, J.; Belevičius, R.; Šešok, D.; Kaunas, J.; Mačiūnas, D. 2012. On Bayesian Approach to Grillage Optimization, *Information Technology and Control* 41(4): 332–339. ISSN 1392-124X. (Thomson ISI Web of Science).

Mačiūnas, D.; Belevičius, R. 2012. Multi-Objective Optimization of Grillages Using Adaptive Genetic Algorithm, *International Review of Mechanical Engineering* 6(3): 432–439. ISSN 1970-8734. (Scopus).

Mačiūnas, D.; Kaunas, J.; Šešok, D. 2012a. Optimization of Grillages With Genetic Algorithms Integrating MatLab and Fortran Environments, *Science – Future of Lithuania / Mokslas – Lietuvos ateitis: Mechanika, medžiagų inžinerija, pramonės inžinerija ir vadyba* 4(6): 564–568. ISSN 2029-2341 (print), ISSN 2029-2252 (online). (Index Copernicus).

Belevičius, R.; Mačiūnas, D.; Šešok, D. 2011. The Minimization of Moments and Reactive Forces in Grillages With a Genetic Algorithm, *Engineering Structures and Technologies / Statybinės konstrukcijos ir technologijos* 3(2): 56–63 (in Lithuanian). ISSN 2029-2317 (print), ISSN 2029-2325 (online). (Index Copernicus).

Mačiūnas, D.; Belevičius, R.; Kaunas, J. 2011. Multi-Objective Optimization of Grillages Applying the Genetic Algorithm, *Science – Future of Lithuania / Mokslas – Lietuvos ateitis: Mechanika, medžiagų inžinerija, pramonės inžinerija ir vadyba* 3(6): 47–52 (in Lithuanian). ISSN 2029-2341 (print), ISSN 2029-2252 (online) (Index Copernicus).

In the other editions

Mačiūnas, D.; Belevičius, R.; Šešok, D. 2012b. Multi-Objective Optimization of Grillages Using Genetic Algorithm With Parallel Strategy, in *Proceedings of the 1st Virtual International Conference on Advanced Research in Scientific Area (ARSA 2012),* held in Zilina, Slovakia, on 3–7 December, 2012. EDIS-Publishing Institution of the University of Zilina, 1842–1848. ISSN 1338-9831, ISBN 978-80-554-0606-0 (Scopus).

Mačiūnas, D. 2012. Multi-Objective Approach to Grillage Optimization With Genetic Algorithm, in *Proceedings of the 17th International Conference "Mechanika-2012"*, held in Kaunas, Kaunas University of Technology on 12–13 April, 2012. Kaunas: Technologija, 176–181. ISSN 1822-2951. (Academic Search Complete).

About the author

Darius Mačiūnas was born in Panevėžys on 11th August, 1978.

He acquired Bachelor's Degree of Engineering Mechanics in 2000 and Master's Degree in the same field in 2002, both from Faculty of Technology, Šiauliai University (ŠU). In 2002–2009 he has worked as an engineer (engineer-constructor, chief engineer) in manufacturing companies. 2009–2013 he is a PhD student at Vilnius Gediminas Technical University in Department of Engineering Mechanics. From 2010 he has been working as an assistant and a lecturer in Department of Engineering Mechanics at Vilnius Gediminas Technical University. In 2012 he has participated in an internship at the University of Tartu (Tartu, Estonia).

DAUGIAKRITERIS GLOBALUS SIJYNŲ OPTIMIZAVIMAS GENETINIAIS ALGORITMAIS

Problemos formulavimas ir darbo aktualumas. Sijynų optimizavimo rezultatai turi didelę reikšmę ekonominiu požiūriu, nes ypatingai svarbu gebėti greitai suprojektuoti pigią ir tuo pačiu racionalią bei patvarią konstrukciją. Todėl inžineriniu požiūriu šios problemos sprendimo rezultatai turi didelę reikšmę kuriant efektyvią sijynų optimizavimo technologiją. Sijynai – sudaryti iš polių ir jungiančiųjų sijų – yra labai efektyvios ir paplitusios polinių pamatų inžinerinės konstrukcijos. Šiame darbe dėmesys bus skiriamas iki šiol dar nepakankamai išnagrinėtam sijynų topologijos ir matmenų sinchroniniam optimizavimui. Šioje disertacijoje topologijos optimizavimas suprantamas kaip optimalios polių išdėstymo po jungiančiosiomis sijomis schemos ieškojimas esant duotam polių skaičiui, o matmenų optimizavimas – kaip jungiančiųjų sijų skerspjūvio optimalių matmenų ieškojimas, laikant, kad visų sijų skerspjūvis vienodas. Darbe bus bandoma apjungti topologijos ir matmenų optimizavimą į vieną algoritmo žingsnį, tuo padidinant tikimybę gauti geresnį optimizavimo sprendinį. Ši problema yra daugiakriterio globalaus optimizavimo uždavinys. Iki šiol tokie didelės apimties uždaviniai nėra iki galo išspręsti, nes jie yra pakankamai sudėtingi: tenka optimizuoti nuo didelio projektavimo kintamųjų skaičiaus priklausančią kompromisinę tikslo funkciją.

Apytikriai galima laikyti, kad sijynai, kurie turi mažiausią įmanomą polių skaičių bei kurių jungiančiosios sijos yra mažiausio skerspjūvio, yra pigiausi. Matematiniu požiūriu tokių sijynų projektavimas yra globaliosios optimizacijos uždavinys, apjungiantis du skirtingus optimizavimo uždavinius: sijyno optimizavimą siekiant mažiausių absoliutiniu dydžiu lenkimo momentų jungiančiosiose sijose bei sijyno optimizavimą siekiant mažiausių atraminių reakcijų poliuose. Akivaizdu, kad galima vienu metu spręsti abu šiuos uždavinius taikant kompromisinę tikslo funkciją su parenkamais svoriniais koeficientais atraminėms reakcijoms bei lenkimo momentams optimizuoti. Optimizavimo (šiuo atveju minimizavimo) uždavinio projektavimo kintamieji yra polių padėtys po sijynu bei jungiančiųjų sijų skerspjūvio matmenys. Optimizavimo kriterijai yra atraminės reakcijos jėga poliuje ir lenkimo momentas jungiančiojoje sijoje.

Tyrimų objektas. Darbe nagrinėjamos mechaninės sijynų konstrukcijos, apkrautos statine apkrova. Sprendžiamas tokių konstrukcijų daugiakriteris globalus optimizavimo uždavinys.

Darbo tikslas ir uždaviniai. Darbo tikslas – sukurti skaičiavimo technologiją, kuri leistų, panaudojus genetinį algoritmą (GA), atlikti nagrinėjamos inžinerinei praktikai aktualios apimties sijynų topologijos bei matmenų sinchroninį optimizavimą.

Darbo tikslui pasiekti yra suformuluoti tokie uždaviniai:

1. Atlikti mokslinės literatūros apžvalgą apie sijynų pagrindinius globalaus ir daugiakriterio optimizavimo metodus.
2. Pritaikius GA koncepciją, sukurti ir išbandyti skaičiavimo technologiją kuri leistų optimizuoti atskirai sijynų topologiją ir sijynų sijų skerspjūvio matmenis.
3. Pritaikius GA koncepciją, sukurti ir išbandyti skaičiavimo technologiją sinchroniniam sijynų topologijos bei matmenų optimizavimui.
4. Pritaikius adaptyvaus genetinio algoritmo (AGA) koncepciją, sukurti ir išbandyti skaičiavimo technologiją sinchroniniam sijynų topologijos bei matmenų optimizavimui.
5. Pritaikius genetinio algoritmo su paskirstymo strategija (angl. *distribution strategy*) (GAPS) koncepciją, sukurti ir išbandyti skaičiavimo technologiją sinchroniniam sijynų topologijos bei matmenų optimizavimui.

Tyrimų metodika. Darbe taikomi skaitiniai skaičiavimo ir sprendimo metodai. Tikslo funkciją sudaro didžiausia poliaus atraminė reakcija ir didžiausias absoliutiniu dydžiu lenkimo momentas jungiančiojoje sijoje ir abu šie kriterijai turi parenkamus svorius. Šią tikslo funkciją siekiama minimizuoti, nepažeidžiant iš anksto nustatytų apribojimų uždaviniui. Tikslo funkcijos reikšmės nustatymas bei apribojimų tikrinimas realizuotas baigtinių elementų metodo pagalba, originalia programa, sukurta VGTU Teorinės mechanikos katedros kolektyvo. Ši programa buvo pritaikyta, kad būtų tinkama nagrinėjamo uždavinio sprendimui. Optimizavimo uždavinys sprendžiamas originaliu genetinių algoritmu. Visos skaičiavimams naudotos programos yra originalios ir sukurtos autoriaus. Programos ir algoritmai yra patikrinti baigtinių elementų programiniu paketu ANSYS.

Darbo mokslinis naujumas

1. Pritaikius GA koncepciją, pasiūlyta ir įgyvendinta originali programinė sijynų sinchroninio topologijos ir matmenų optimizavimo technologija. Ši skaičiavimo technologija suteikia galimybę vienu metu siekti dviejų tikslų: nustatyti optimalią polių išdėstymo schemą bei nustatyti optimalius sijų skerspjūvio matmenis – tokiu būdu sprendžiamas mišrus topologijos optimizavimo-matmenų nustatymo uždavinys.
2. Pritaikius adaptyvaus GA (AGA) koncepciją, pasiūlyta ir įgyvendinta originali programinė sijynų sinchroninio topologijos ir matmenų optimizavimo technologija. Ši skaičiavimo technologija suteikia galimybę gauti vidutiniškai 3% geresnius optimizavimo rezultatus (mažesnes tikslo funkcijos reikšmes) nei taikant GA koncepciją.
3. Pritaikius GA su paskirstymo strategija (GAPS) koncepciją, pasiūlyta ir įgyvendinta originali programinė sijynų sinchroninio topologijos ir matmenų optimizavimo technologija. Ši skaičiavimo technologija suteikia galimybę gauti vidutiniškai 5% geresnius optimizavimo rezultatus (mažesnes tikslo funkcijos reikšmes) nei taikant GA koncepciją.

Darbo rezultatų praktinė reikšmė. Pasiūlytos skaičiavimo technologijos ir gauti tyrimų rezultatai tinkami inžinerinei praktikai priimtinos apimties polinių pamatų sijynų optimizavimo uždavinių sprendimui. Pritaikius GA, paprastai randami keli racionalūs sprendiniai su artimomis tikslo funkcijų reikšmėmis, tačiau atitinkančias skirtingas sijynų schemas. Tai naudinga inžinerinėje praktikoje, kadangi projektuotojas gali rinktis jam priimtinesnę sijyno schemą.

Ginamieji teiginiai

1. Pritaikius adaptyvaus GA (AGA) koncepciją, pasiūlyta programinė sijynų sinchroninio topologijos ir matmenų optimizavimo technologija,

kuri suteikia galimybę gauti vidutiniškai 3% geresnius optimizavimo rezultatus (mažesnes tikslo funkcijos reikšmes) nei taikant GA koncepciją.

2. Pritaikius GA su paskirstymo strategija (GAPS) koncepciją, pasiūlyta programinė sijynų sinchroninio topologijos ir matmenų optimizavimo technologija, kuri suteikia galimybę gauti vidutiniškai 5% geresnius optimizavimo rezultatus (mažesnes tikslo funkcijos reikšmes) nei taikant GA koncepciją.

Darbo rezultatų aprobavimas. Disertacijos rezultatai paskelbti 7 moksliniuose straipsniuose ir pristatyti 8 mokslinėse konferencijose, iš jų 3 – tarptautinės.

Darbo apimtis. Disertaciją sudaro įvadas, trys skyriai, išvados, literatūros šaltinių ir autoriaus publikacijų sąrašai bei trys priedai. Darbo apimtis yra 120 puslapių įskaitant priedus, tekste panaudoti 50 paveikslų ir 16 lentelių. Rašant disertaciją buvo panaudoti 186 literatūros šaltiniai.

Disertacijos įvade aprašomas problemos aktualumas, formuluojamas darbo tikslas bei uždaviniai, aprašomas mokslinis darbo naujumas bei tyrimų metodika, pateikiami ginamieji teiginiai.

Pirmasis skyrius skirtas literatūros apžvalgai: sijynų pagrindiniams globalaus ir daugiakriterio optimizavimo metodams. Pagrindžiamas genetinių algoritmų (GA) pasirinkimas.

Antrajame disertacijos skyriuje aprašyta kaip pritaikyti GA koncepciją sijynų topologijos optimizavimui. Formuluojama optimizavimo problema. Pateikiami sijynų topologijos optimizavimo rezultatai.

Trečiame skyriuje aprašyta kaip pritaikyti GA koncepciją sijynų sinchroniniam topologijos ir matmenų optimizavimui. Pateikiami optimizavimo uždavinio sprendiniai, kai tikslo funkcijos kriterijų įtaka optimizavimo uždaviniui yra vienoda bei panaudojus adaptyvų genetinį algoritmą ir genetinį algoritmą su paskirstymo strategija.

Disertacijos bendrosios išvados apibendrina darbo rezultatus ir jų reikšmę.

Bendrosios išvados

1. Sijynų daugiakriteriam globaliajam optimizavimui labiau tinkami yra stochastiniai globalaus optimizavimo algoritmai, iš kurių genetiniai algoritmai yra vieni pranašiausių.

2. Remiantis nustatyta priklausomybe tarp dviejų tikslo funkcijos kriterijų reikšmių ir svorinių koeficientų santykio reikšmių, galima pasirinkti įvairias sijynų schemas, priklausomai nuo to, kuris iš kriterijų (atraminė

reakcija poliuje ar lenkimo momentas sijoje) turės didesnę, mažesnę ar vienodą įtaką optimizavimo uždaviniui. Tai gali būti naudinga inžinerinėje praktikoje, nes projektuotojas gali rinktis jam priimtinesnę sijyno schemą.

3. Panaudojus GA, sukurta skaičiavimo technologija sijynų sinchroniniam topologijos ir matmenų optimizavimui. Pritaikius šią technologiją, gali būti nustatyti visi galimi Pareto optimalūs sprendiniai.

4. Panaudojus AGA, sukurta skaičiavimo technologija sijynų sinchroniniam topologijos ir matmenų optimizavimui. Pritaikius šią technologiją, gauti vidutiniškai 3% geresni rezultatai (t. y. mažesnės tikslo funkcijos reikšmės) nei naudojant klasikinį GA. Dėl padidėjusio konvergavimo greičio AGA vidutiniškai du kartus sumažina skaičiavimo laiką, kuris yra lemiamas veiksnys visiems globaliojo optimizavimo uždaviniams.

5. Panaudojus GAPS, sukurta skaičiavimo technologija sijynų sinchroniniam topologijos ir matmenų optimizavimui. Pritaikius šią technologiją, gauti vidutiniškai 5% geresni rezultatai (t. y. mažesnės tikslo funkcijos reikšmės) nei naudojant klasikinį GA.

Trumpos žinios apie autorių

Darius Mačiūnas gimė 1978 m. rugpjūčio 11 d. Panevėžyje.

2000 m. įgijo mechanikos inžinerijos bakalauro laipsnį, o 2002 m. – mechanikos inžinerijos magistro laipsnį Šiaulių universiteto Technologijos fakultete. 2002–2009 m. dirbo inžinerinį darbą (inžnieriumi-konstruktoriumi, vyr. inžinieriumi) gamybinėse įmonėse. 2009–2013 m. – Vilniaus Gedimino technikos universiteto doktorantas. Per visą studijų laikotarpį doktorantas dirbo pedagoginį, mokslinį ir metodinį darbą Vilniaus Gedimino technikos universiteto Teorinės mechanikos katedroje. 2012 m. dalyvavo stažuotėje Tartu universitete (Tartu, Estija).

Darius MAČIŪNAS

MULTI-OBJECTIVE GLOBAL OPTIMIZATION OF GRILLAGES USING GENETIC ALGORITHMS

Summary of Doctoral Dissertation
Technological Sciences, Mechanical Engineering (09T)

Darius MAČIŪNAS

DAUGIAKRITERIS GLOBALUS SIJYNŲ OPTIMIZAVIMAS GENETINIAIS ALGORITMAIS

Daktaro disertacijos santrauka
Technologijos mokslai, mechanikos inžinerija (09T)

2013 05 02. 1,5 sp. l. Tiražas 70 egz.
Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
http://leidykla.vgtu.lt
Spausdino UAB „Ciklonas“
J. Jasinskio g. 15, 01111 Vilnius