Genetic Algorithms with Steel Structures
A Literature Review

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A study of research done on genetic algorithms in steel structure design

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I. Introduction

Presented here is a literature review of several research publications investigating improved methods of optimization of steel structures using genetic algorithms. The different research topics have been divided into three categories: Specialized Structure Designs, Genetic Algorithm Improvements, and Optimization Goals.

Specialized Structure Designs involve genetic algorithms that are tailored to specific structure types. Some of these designs will include trusses, two dimensional frames, three dimensional frames, lattice towers, and pitched roof tops.

Genetic Algorithm Improvements include the research done to enhance the robustness of the optimization program. This section will include research improving execution time, crossover techniques, bilevel networking, fuzzy operators, and tournament selection.

Optimization Goals focuses on the genetic algorithms designed specifically to improve the optimization of one or more objectives. Some of these objectives include member size, shape, topology, damage detection, and vibration control.

II. Specialized Structure Designs

Saka, M.P. (2003). "Optimum design of pitched roof steel frames with haunched rafters by genetic algorithm." ***Computers & Structures, 81*, 1967**

This genetic algorithm is specifically designed for the optimization of steel-framed pitched roofs with haunches for the rafters and the eaves. The genetic algorithm correlated the cost (or weight) of the haunch to the size and length in order to develop the ideal design. The British Standard 5950 is also integrated into this program to apply serviceability and strength constraints on the design. The buckling and torsion of columns and rafters are also analyzed in this genetic algorithm.

Rajan, S.D. (1995). "Sizing, shape, and topology design optimization of trusses using genetic algorithm." ***Journal of Structural Engineering*, 121, 1480-1487**

A review of the design problem formulation is given in this paper to familiarize the reader with the design criteria that will be used and their functions. A section also touches on special issues that a user might want to take into account such as unstable structures, lack of structural deformation, using restarts, and repeating chromosomes.

In this article there are three main design criteria that are involved in the optimization: sizing, shape, and topology. A combination of discrete and continuous design variables are used for the cross-sectional area of the members. For the topology (or nodal location) a continuous design variable is used to find the best location.

Sivakumar, P.; Rajaraman, A.; Knight, G.M. Samuel; Ramachandramurthy, D.S. (2004). "Object-oriented optimization approach using genetic algorithms for lattice towers." ***Journal of computing in Civil Engineering*****, 18, 162-171**

This is a study performed on the design improvements of steel lattice towers using a combination of a genetic algorithm and an object-oriented approach. The genetic algorithm is performed in the traditional manner on the lattice tower, but in addition, it is accompanied by an object-oriented approach.

Each bay of the tower is considered an object and treated as one member. Being treated as one member reduces the search space needed and helps the execution converge faster. Symmetry of the structure and the loading in all four directions helps form the basis for the grouping of members into objects. These factors reduce computational time and power required by the computer.

Camp, Charles; Pereshk, Shahram; Cao, Guozhong (1998). "Optimized design of two-dimensional structures using a genetic algorithm." ***Journal of Structural Engineering*****, ASCE, 124 (5), 551-559**

The research in this article includes a design procedure of a simple genetic algorithm for discrete optimization of *two*-dimensional structures. The objective function of the research is the weight (or cost) which is minimized in correlation to the serviceability and strength requirements. To complete this optimization, a program was developed based on a simple genetic algorithm for optimization called FEAPGEN. FEAPGEN is a module incorporated into a modified version of a Finite Element Analysis Program (FEAP). This program includes special features such as discrete design variables, open format for designed constraints, design checks using AISC-ASD specification, and multiple loading conditions.

Camp, Charles; Pereshk, Shahram; Cao, Guozhong. (1997). "Optimized steel frame design using a genetic algorithm." ***Structures Congress*****, 2, 803-807**

The research done in this study involves the discrete optimization of *three*-dimensional framed structures. The objective function of the research is the weight (or cost) which is minimized in correlation to the serviceability and strength requirements. To complete this optimization, a program was developed based on a simple genetic algorithm for optimization called FEAPGEN. FEAPGEN is a module incorporated into a modified version of a FEAP as was mentioned in the prior study by the same authors. This program includes special features such as discrete design variables, multiple loading conditions, live load patterns, an open constraints format, nodal displacements, element stresses checked using AISC-ASD specification, and practical construction considerations.

III. Genetic Algorithm Improvements

Adeli, Hojjat; Kumar, Sanjay. (1995). "Distributed genetic algorithm for structural optimization." ***Journal of Aerospace Engineering*****, 8, 156-163**

The purpose of the research performed in this paper is to find ways to improve the execution time for the computation of the genetic algorithm. What Adeli and Kumar proposed was the connection of several computers together in a parallel network link. The networking between the computers was not done by the Internet but rather was connected by high speed Ethernet (direct networking). This connection enabled the computation load to be handled by several different computers as opposed to just one, thus increasing the execution speed.

The data in the conclusion of their research supports this procedure in that the parallel computer connection can improve the efficiency of an execution not by reducing necessary computation but by distributing it and reducing the time needed for the computation.

Gero, M.B.P.; Garcia, A.B.; Diaz, J.J.C. (2005). "A modified elitist genetic algorithm applied to the design optimization of complex steel structures." ***Journal of Constructional Steel Research*****, 61, 195-205**

Two main differences are found through the research of this paper. The first is the phenotype crossover operator. Instead of the traditional crossover operators that interchange random bits of information between the break up of the string design variables, the phenotype crossover break is located between two phenotypes or design variables. This procedure will crossover design variables to other strings but leave each of the design variables in tacked.

The second is an aptitude selection operator that has been added to the program to prevent isolated individuals or "strangers" from evolving and altering subsequent generations in an unwanted fashion. This enables future generations to continue to be created by the best designs of the previous ones and avoids isolated elements from continuing on.

Sarma, Kamal C. (2001). "Bilevel parallel genetic algorithms for optimization of large steel structures." ***Computer-aided Civil and Infrastructure Engineering,*** **16, 295-304**

In this research the main focus is on optimization of very large steel structures subject to the constraints of LRFD and ASD specifications on high-performance multiprocessor computers. In addition to the parallel fuzzy genetic algorithms performed, the program execution is done on a bilevel stage. This is when two different parallel processes can both be performed at the same time on two different levels and with two different parallel processing paradigms.

In this paper, two different versions of bilevel parallel genetic algorithms are presented and evaluated. One genetic algorithm has processor farming and the other with migration message passing.

Sarma, Kamal C.; Adeli, Hojjat. (2000). "Fuzzy genetic algorithm for optimization of steel structures." ***Journal of Structural Engineering*****, 126, 596-6004**

In the early stages of an execution there can be solutions discarded prematurely because of a minor violation in any of the constraints. Occasionally, these premature candidates have the potential to evolve into robust solutions; however, because of the strict elimination process, their potential is never reached.

This research performed by Sarma and Adeli, on the genetic algorithm of a steel structure, focuses on a fuzzy augmented Lagrangian genetic algorithm. A fuzzy genetic algorithm will allow eliminated candidates in the early phases of the execution to remain in the gene pool for what is considered a second chance at evolution. This execution process will increase the chance of obtaining a global optimum.

Yang, Jiaping. (1997). "Structural optimization by genetic algorithms with tournament selection." ***Journal of Computing in Civil Engineering*****, 123, 375**

The genetic algorithm is used in this article with the tournament selection scheme to find the optimization of a structure's design. A comparative analysis exists between the differences of a genetic algorithm using the tournament selection approach and one using the roulette wheel selection approach for truss designs.

The genetic algorithm involving the tournament selection analyzed in this article is stated to search for optimum solutions in a more efficient way than the roulette wheel method. Because of this, the program will have a greater potential for solving a wide variety of optimization problems.

Pezeshk, S.; Camp, C. V.; Chen, D. (2000). "Design of non-linear framed structures using genetic optimization." ***Journal of Structural Engineering*****, 126, 382-388**

Authors of this research focus on the difference between a linear optimization model and a nonlinear optimization model using genetic algorithms. A group selection scheme is used for reproduction instead of traditional methods such as proportionate reproduction, tournament selection, ranking selection, steady-state selection, and greedy over selection. A modified form of the adaptive crossover scheme is also used which was developed by Spears (1994).

A comparison of three different cases is displayed at the conclusion of this study. The first is a linear model ignoring P-Δ. The second is the same linear model with the P-Δ included. The third is the nonlinear model with the P-Δ also included.

IV. Optimization Goals

Anthony, D.K. (2003). "Robust-optimal design of a lightweight space structure using a genetic algorithm." ***AIAA Journal*****, 41, 1601**

All steel-structure designs must be tested statically but also dynamically. The vibration of a structure under any given load can be greatly altered by miniscule changes to the geometry of the design. After these perturbations are performed, the average vibration of the structure is reevaluated and compared to previous results.

Two different methods are addressed in this article to evaluate the robust optimization of a structural design that is incorporated into a genetic algorithm. The first is a Computer Experiment Method and the second is a Noisy Phenotype Method. Both methods continuously reevaluate the average energy levels after continuous slight geometric alterations of the design.

Moslem, Kaazem. (2002). "Structural damage detection by genetic algorithms." ***AIAA Journal,*** **40, 1395**

Genetic algorithms are not just used for the design of structures but also for damage detection. The detection, location, and estimate of damage in a structure without major disruption to the building operations or superstructure, can greatly benefit those responsible for repairs.

This article presents a two-stage detection method based on the work of Kim and Bartkowicz to locate possible areas of damage. Stage one is to locate the possible areas of damage and stage two is to estimate the extent of the damage. After these two steps have been completed, the necessary preparations can be made to have the damaged areas of the structure repaired.

Pereyra, V.; Lawver, D.; Isenberg, J. (2003). "An algorithm for optimal design of steel frame structures." ***Applied Numerical Mathematics*, 47, 503-514**

The research done by Pereyra, Lawver, and Isenberg focuses on the combination of a standard finite element structural design code with an optimization program. The goal of merging these two components together is to reduce the weight of a structure subject to wind and gravity loads. This combined system can create a compliant design from one that is not compliant and at the same time, reduce the weight while holding the constraints fixed.

Shrestha, Sharad Man; Ghaboussi, Jamshid. (1998). "Evolution of optimum structural shapes using genetic algorithm." ***Journal of Structural Engineering*, 124, 1331-1338**

The purpose of this article is to study the different structural shapes that can be created with an evolutionary genetic algorithm. Most of the shapes we see today in structures are developed conceptually by someone's imagination and incorporated in a structural design. The goal here is to leave all constraints of the geometry and topology free in the genetic algorithm and allow the program to invent its own optimized shape. In simple structures, the optimized shape might be similar to a conventional shape in common use; but, in complicated structural models, new and innovative designs can be created.

Soh, Chee Kiong. (1996). "Fuzzy controlled genetic algorithm search for shape optimization." ***Journal of Computing in Civil Engineering*****, 10, 143**

The fuzzy concept applied to genetic algorithms is a method that allows certain strings of information to continue on to future generations when normally they would have been eliminated. This article uses hybrid fuzzy genetic algorithms for the design of steel trusses. By using this approach, the lightest weight designs have been developed with an optimal shape. This example shows that the fuzzy genetic algorithm can also reduce computational time and improve efficiency.

Toropov, V.V.; Mahfouz, S.Y. (2001). "Design optimization of structural steelwork using a genetic algorithm, FEM and a system of design rules." ***Engineering Computations*****, 18, 437-459**

This article incorporates the integration of a genetic algorithm, a finite element model, and a system of structural design rules taken from British Standards (BS 5950 and BS 6399).

The focus of this research is discrete design optimization of structural steelwork and the effect of different approaches used for determining the effective buckling length of a column as part of the optimum design. The objective function in this problem is the total weight of the structure (which is directly related to the cost). The optimization of cross-sectional properties of the members will determine the outcome of the structure's weight.

Hayalioglu, M.S. (2000). "Optimum design of geometrically non-linear elastic-plastic steel frames via genetic algorithm." ***Computers & Structures*, 77, 527-538**

In this paper, the optimum design of geometrically non-linear frames made of elastic-plastic material is analyzed with a genetic algorithm. The non-linear, elastic-plastic frame is compared to a linear-elastic frame using a genetic algorithm to determine which method proves to be most accurate.

The non-linear, elastic-plastic frames tend to have larger displacements than the linear frames but less stress in the members. A disadvantage to using a non-linear genetic algorithm is that the execution time takes much longer. The prolonged execution time occurs because each load increment requires four to ten times the iterations to complete the equation.

Yang, Yaowen (2005). "Integrated optimal design of vibration control system for smart beams using genetic algorithms." ***Journal of Sound & Vibration*, 282, 1293**

In flexible structures, the vibration control has been a major research topic recently; however, the use of piezoelectric patches and feedback control gains in steel structures has rarely been researched. Instead of using optimization for the design of the structure, this research uses optimization for the placement and location of these patches throughout the steel frame.

To solve this problem, an integer-real-encoded genetic algorithm has been developed to compute and solve this discrete-continuous optimization problem. If placed in optimal locations, vibration throughout the structure can be reduced and feedback from these locations can be received and analyzed.