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An Overview of Structural Design Optimization of Buildings

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Abstract – This examination presents investigate investigating the capability of topology optimization as a methods for the design of supportable building components. Topology optimization is a mathematical, angle based design procedure that can be utilized to decide the dissemination of required material inside a design space in view of characterized loads and limit conditions while meeting a recommended target objective, for example, limiting diversion. The idea of topology optimization has been used by the automotive and aerospace industry for right around thirty years now. Since its initial advancement, where issues related with solutions intended to fulfill most extreme stiffness with least weight are absolutely critical. The current immersions of advanced design tools and techniques inside the engineering industry have driven an ever increasing number of draftsmen to look for computationally determined, data-centric. Methodologies to aid the design procedure. Topology optimization is appropriate as a methodology to aid the advancement of frame that is established in sound structural rationale while taking a stab at material proficiency. This examination presents contextual investigations of late design projects that use topology optimization for projects running from long-traverse rooftop structures to high-rise buildings. Advances in cutting edge producing are additionally analyzed as a method for all the more effortlessly acknowledging feasible building systems through this utilization of topology optimization. The exploration and results displayed add to setting up a structural optimization toolbox for design work on, showing important method augmentations and contemplations and practical outcomes that are straightforwardly pertinent to building projects.

Keywords: Structural Design, Optimization, Buildings, Topology, Material Proficiency, Building Systems, Building Projects, etc.

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INTRODUCTION

A lot of research concerning the design optimization of steel structures is drawn in literature with the focus on cost reduction and weight optimization. Indeed, the scope of steel structures regards several application fields such as civil buildings, bridges, factories, stores, and power plants. Typical onshore and offshore oil & gas constructions are steel structures with horizontal and vertical beams and decks. Many examples of oil & gas steel structures, called modules, are used in power generation plants and also in upstream and downstream activities. In particular, the oil & gas markets have an ever growing demand for “plug-and-play” onshore and offshore solutions to mitigate issues that may interfere with smooth construction operations at the final installation site. Typically, those plug & play solutions are achieved through the modularization of functionally independent parts of a plant. Such modules are constructed and tested in a “controlled” environment and then transported to the final destination minimizing the site work’s and the risks for the customer. Based on this, gas compression and power generation modules can range from simple configurations to large modules that include both turbo compression and gas processing equipment in the same prefabricated structure. The average steel structure self-weight may raise over 600 tons per module. Due to their typical functionality the modules are subjected to static loads, dynamic loads, land transport loads, sea transport and fatigue loads. The weight optimization of steel constructions is a very important issue in the field of the oil & gas industry. In fact, the cost of a steel module is related to the structures self-weight, the number of beams, the types of beam sections, the number of overstressed beams and the type of construction. Simulation tools based on FEM analysis are used in the design of big steel structures due to the possibility to investigate the behavior of mechanical structures with virtual prototypes. Simulations with optimization analysis are proposed in many research activities in order to achieve the absolute maximum or minimum values of predefined objective functions. One of the most famous types of the optimization procedures is the solution through genetic algorithms. In particular, genetic algorithms are proposed in a large number of optimization studies for different purposes. The following sections describe the research background regarding the structural optimization paying attention to mathematical algorithms and solution procedures used in literature. Some background research proposes a design optimization methodology; however the design of oil & gas structures requires a more complex and dedicated approach for different reasons. In fact, many researchers propose the optimization analysis of simple structures without a parallel analysis of load conditions. Many test cases of structures regard simple trusses or portals and the considered analysis are focused on static or at least dynamic loading. In addition, past projects do not consider the interaction between the design methodology and the work of the engineer in order to reduce the design time. Whilst, the intent of the method proposed in this study is to define a reusable methodology to support the design optimization of big steel structures with attention to design time and different loading cases. The application of this approach at the early design phase could be very suitable to achieve a better project of mass reduction in the next executive phase with money saving benefits. A platform-tool has been developed to support the automatic optimization of steel frames using genetic algorithms. A test case is proposed to investigate the re-design of a lightweight module analyzing different solutions of steel beam grouping. The test is limited to the following load cases: static, sea transport, and land transport. The structure in subset is a typical power generation module with a heavy duty gas turbine (GT > 80 MW). The module is equipped with HVAC systems, bridge cranes, etc.

The genetic algorithms are considered as the most suitable optimization method for the design of beam structures. This decision is because of the effortlessness of the mathematical formulation, the autonomy from target function, the likelihood to work with discrete factors, Prendes Gero et al. characterized a mathematical elitist approach keeping in mind the end goal to build the productivity of the genetic algorithm method. They examined two of the most common 3D structures: a gateway frame structure and a three-story steel building. Genetic algorithms have a place with a kind of evolutionary algorithm utilized for explaining functions of optimization methods. This approach is motivated by nature and the organic model of chromosomes, which contain genetic information spoken to by area and estimation of their qualities. The usage of a genetic algorithm requires the meaning of portrayal, wellness function, parent choice and survivor choice instruments and additionally coordinating and change administrators. Specifically, wellness is the estimation of the target function in an optimization issue.

REVIEW OF LITERATURE:

In GA, a populace of hopeful solutions (people) is developed toward better solutions by an iterative procedure. Every individual has an arrangement of properties called chromosomes which can be changed and modified (hybrid and transformation), and in every age, the wellness of each person in the populace is assessed. The new populace of people is then utilized as a part of the following cycle. The age loop ends when the populace accomplishes an agreeable wellness level or if a most extreme number of ages have been come to.

The greater parts of the structural engineering undertakings are spoken to by complex physical and mathematical issues that are hard to be explained physically. Thus, if the point of a common or mechanical engineering project is to locate an effective design utilizing any of the accessible optimization techniques physically, it is important to make as straightforward a mathematical model as could be expected under the circumstances. This leads a designer to utilize general coefficients to ensure the wellbeing of a design and the design winds up moving far from reality.

Therefore, masters for working exploration and systems of information technologies manage the usage of optimization techniques in mechanical and structural engineering software (Torii, et. al., 2016). There, the designers have the chance to apply complex mathematical algorithms for the formation of a productive design model (Tiirker and Bayraktar, 2013). If there should be an occurrence of taking care of complex structural or mechanical issues characterized by multi-variable design space number of performed emphases may especially impact processing time (Taranath, 2011). It is prescribed to perform for example 3 times 20 irregular cycles started in different point with shifting design space confines instead of 100 arbitrary emphasess in light of similar conditions. This enhances the precision, robustness and time cost of the solution. One method for utilizing optimization methods in structural designs is to actualize them in FEM-based (Finite Element Method) software (Strombcrg et. al., 2012). FEM is at present a standout amongst the most broadly utilized methods in mechanical and structural engineering design for reproductions of genuine systems (Fawzia and Fatima, 2010).

The algorithms of the displayed optimization methods (FOM and SAM) depend on conventional working examination techniques (Reghini, 2013) with specific adjustments for their capacity to tackle multipurpose issues. The effectiveness, robustness, and design space investigation of optimization methods can be enhanced by optimization tools. One of the greatest difficulties in the execution of optimization techniques into engineering systems is their similarity and capacity to comprehend an extensive variety of systematic issues (Pucker and Grabe, 2011). We introduce here a general framework for taking care of structural engineering-related optimization issues by applying mathematical methods set up to locate the insignificant or maximal estimations of a function speaking to the structural design. The rule comprehends the task of most commonly utilized optimization tools and to achieve the optimal model of a system with commercial design tools without high prerequisites for designer aptitudes in science.

The Design Optimization module is an individual module expected for tackling specialized optimization issues inside the Ansys program that applies the finite element method (Jayachandran, 2009). A finite element model which is subjected to an optimization procedure utilizes the principle components of the Ansys program for model creation (model creation pre-processor), (solution processor) and assessment of acquired results (database comes about post-processor). Data stream amid an optimization procedure performed by the Ansys program can be communicated by the accompanying scheme (Fig. 1). From the perspective of a designer, the analysis document is the most essential element of the modeling procedure. It contains the parametrical articulation of a model, parameterization of assessed data from an underlying design and a goal function. The parametrical model incorporates geometrical highlights of the model, which are utilized as a part of the accompanying case as design factors (DVs). The assessed data parameterization presents state factors (SVs) and target function.

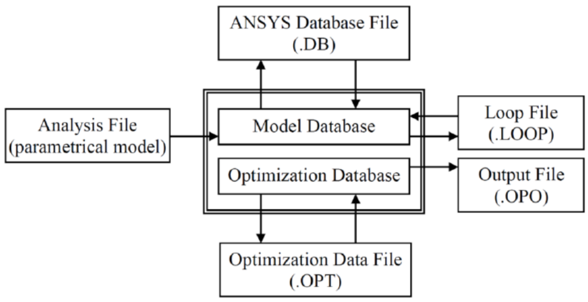

Fig. 1- Data flow during optimization procedure in ANSYS program

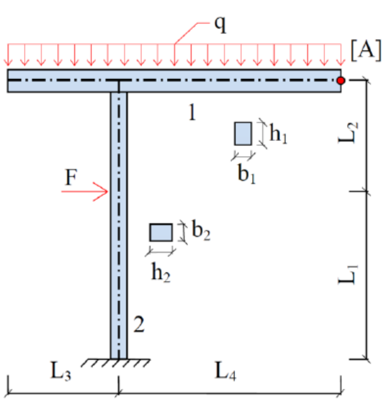

Fig. 2- Three bars" plane frame structure

STRUCTURAL DESIGN OPTIMISATION:

Structural design optimization has achieved significant progresses in recent years. Modern structural optimization techniques combine the finite element analysis with mathematical programming or optimality criteria methods into a single scheme to automatically generate optimal designs. With advances in computer technology, there is no doubt that structural optimization techniques will become essential design tools in design offices. This special issue reflects recent advances in structural design optimization. Optimisation of structural shape and topology is rooted in the work of (Jayachandran, 2009).

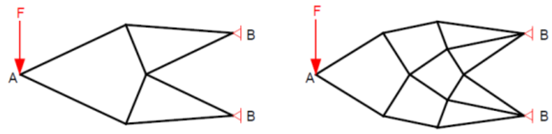

Figure 3: Optimal self-adjoint cantilever trusses with six and eleven joints, subjected to load F at point A and fixed at support points B

His pioneering studies in the field derived conditions for limits of material economy in truss structures, developing structural concepts originally demonstrated (Sirigiri, 2014). In the case of a point-loaded cantilever truss with a circular support, and disregarding the weight of joints, the minimum weight is achieved by a truss-like continuum with an infinite number of joints and bars (Ali and Moon, 2007). Refined this approach by modelling the weight of joints in his minimization problem and employing optimality criteria and the concept of adjoin trusses to derive simple and practical cantilever structures. Nevertheless, these structures, shown in figure 3, are limited in their treatment of constraints and load cases. Although many popular general optimisation methods have been applied or adapted to structural design optimisation tasks, various problem specific methods also exist, in particular to tackle the unique challenges of topological design.

Size optimization- Vast quantities of academic literature exist testing a diverse range of optimization methods on benchmark sizing problems. This section attempts to highlight the most pertinent of these to the issue of integrating size and topology optimisation, since this is the primary role of size optimisation in this paper. Size optimisation problems can easily be expressed mathematically and are traditionally solved by deterministic methods. However, for statically indeterminate structures subject to multiple displacement constraints, the design space is almost invariably multi-modal.

Fully Stressed Design-Fully Stressed Design is most commonly used for structures in which strength considerations govern over stiffness, such as small and medium size frames. Maxwell (1864) recognised that in a statically indeterminate structure, in which members can be resized without influencing the load path of the structure, the minimum weight design is the one in which every member is subjected to the maximum permissible stress in at least one load case, i.e. fully stressed. For indeterminate structures, the number of distinct fully stressed designs can be very large. Conventional procedures increase the size of over-stressed members and reduce the size of under-stressed members, reanalyzing and iterating until convergence is achieved. However, Mueller and Burns (2001) demonstrate that this approach excludes a set of repelling fully stressed designs, in which some members will respond to an increase in size by attracting greater stress. This causes an initial sizing solution in the vicinity of a repelling fully stressed design to rapidly move away from this area of the design space. Mueller and Burns (2001) employ a series of non-linear equations to define the fully stressed state and solve with a hybrid Newton-Monomial method to find sets of fully stressed designs, commencing from randomly generated initial designs.

Evolutionary Algorithms in topology optimization - Although not pure optimisation algorithms (De Jong 1993), Evolutionary Algorithms (EAs) are versatile, stochastic, problem-solving methods, alternatively classified under the name of Evolutionary Computing (EC). This class of methods (not to be confused with Evolutionary Structural Optimisation) is so-called due to its mimicry of natural biological evolution as postulated originally by Charles Darwin (1859). In general, the performance of a population of individual solutions in solving the prescribed problem is assessed according to one or more quantifiable criteria. In turn, performance, commonly referred to as fitness, influences the chances of an individual's involvement in populating the subsequent generation of solutions, by some combination of the genetic operators of reproduction, crossover (or recombination) and mutation. Around the 1960s, three sub-classes of EA were developed independently: Genetic Algorithms (GA) (Holland 1975), Evolutionary Programming (EP), and Evolutionary Strategies (ES). However, these were not brought together under the name of EAs until the 1990s. A fourth class, Genetic Programming (GP), also emerged in the 1990s.

STRUCTURAL OPTIMIZATION FOR SEISMIC DESIGN:

Structural design has dependably been an extremely fascinating and innovative portion in a huge assortment of engineering projects. Structures, obviously, ought to be designed to such an extent that they can oppose connected forces (stress constraints), and don't surpass certain distortions (displacement constraints). In addition, structures ought to be conservative. Hypothetically, the best design is the one that fulfills the stress and displacement constraints, and results at all cost of construction. In spite of the fact that there are numerous elements that may influence the construction cost, the first and most evident one is the measure of material used to build the structure.

Along these lines, limiting the weight of the structure is normally the objective of structural optimization. The primary approach in structural optimization is the utilization of material methods of mathematical programming. Some of these are Linear Programming (LP), Non-Linear Programming (NLP), Integer Linear Programming (ILP), and Discrete Non-Linear Programming (DNLP). Whenever all or part of the design factors are constrained to sets of design esteems, the issue solution will utilize discrete (direct or non-straight) programming, which is of extraordinary significance in structural optimization. Indeed, when the design factors are functions of the cross sections of the members, which is the situation for most structural optimization issues, they are regularly browsed a constrained arrangement of accessible sections. For example, steel structural elements are looked over standard steel profiles (e.g., WF, and so forth.), structural timber is given in specific sizes (e.g., 4x8, and so on.), concrete structural elements are typically designed and developed with discrete dimensional additions to the entire inch, and brick work buildings are worked with standard size pieces (e.g., 8", or 10").

Another essential issue to call attention to is that the idea of structural optimization issues is typically nonlinear and non-arched. Thusly algorithms for mathematical programming may join to nearby optima rather than a worldwide one. At last, there has dependably been the method of Total Enumeration for discrete optimization issues. In this method, every conceivable blend of the discrete esteems for the design factors are substituted, and the one bringing about the base an incentive for the goal function, while fulfilling the constraints, is picked. This method dependably finds the worldwide least yet is moderate and impractical. Be that as it may, some recently created techniques, known as heuristic methods, give methods for finding close optimal solutions with a sensible number of emphasess. Incorporated into this gathering are Simulated Annealing, Genetic Algorithms, and Tabu Search. In addition, the decrease in calculation cost as of late, because of the accessibility of speedier and less expensive computers, makes it possible to perform more calculations for a superior outcome. As far back as the nineteenth century, built up a few hypotheses identified with objective design of structures, which were additionally summed. In the 1940's and 1950's, out of the blue, some practical work in the zone of structural optimization was finished.

Tabu Search starts similarly as common nearby or neighborhood seek, continuing iteratively starting with one solution then onto the next until the point that a tasteful solution is gotten. Traveling between various solutions is known as a move. Tabu inquiry begins like the steepest drop method. Such a method just allows moves to neighbor solutions that enhance the present target function esteem. A depiction of the different strides of the steepest plunge method is as per the following.

1. Pick a plausible solution (one that fulfills all constraints) to begin the procedure. This solution is the present best solution.

2. Output the whole neighborhood of the ebb and flow solution looking for the best possible solution (one with the most alluring estimation of target function).

3. In the event that no such solution can be discovered, the present solution is the neighborhood optimum, and the method stops.

Recurrence based memory is a kind of long haul memory that gives information that supplements the information gave by regency-based memory. Fundamentally, recurrence is estimated by the counts of the quantity of events of a specific occasion. The usage of this kind of memory is by doling out a recurrence punishment to already picked moves. This punishment would influence the move estimation of that specific move in future cycles.

It is aggressively restrictive to locate the optimal solution of the above structural optimization issue. In any case, Tabu Search can be utilized to locate a close optimal solution. In such an issue, the design factors are the cross sections for the structural elements and are browsed a set (or sets) of accessible sections arranged by their weight per unit length (or cross sectional region). The target function to be limited is the weight of the structure that is ascertained by summing the result of weight per unit length by length for every structural element. A move at that point comprises of changing the cross section of an element to one size bigger or one size littler. In this way, for a frame with n structural elements there will be 2xn moves at any time amid the pursuit. The constraints are the stresses in the structural elements and the between story floats for all story levels. The considered stresses are bending, consolidated pivotal and bending, and shear stresses.

The beginning stage of the hunt must be a structural design that fulfills the stress and displacement constraints. The pursuit starts by assessing the frame weight at the whole neighborhood of the beginning stage and the comparing move esteems, picking the best move (the one that outcomes in the most weight decrease). The required substitutions are then made to the structural properties, and structural analysis is performed. In view of the analysis results, stress and displacement constraints are checked. On the off chance that the greater parts of the constraints are fulfilled, the move is possible and the hunt algorithm has discovered another hub. On the off chance that any of the constraints are not fulfilled, the structural setup is set back to its unique shape, the second best move is chosen, the comparing changes are made to the structural model, and the analysis and requirement assessment forms are rehashed. This procedure is preceded until a move that fulfills every one of the constraints is found. The inquiry algorithm is presently at another hub. At this stage, the tabu residency and recurrence punishment for the performed move are connected to the chosen move and the program continues by rehashing a similar algorithm at the new hub.

CONCLUSION:

This work can additionally be stretched out to three dimensional structures to advance its structural execution, for example, the tip displacement, recurrence, consistence, basic clasping load, and so forth. A synchronous sizing, shape and topology optimization methodology is created and utilized for the optimal design of tall buildings modeled as planar frames. The created framework takes into account researching the design efficiencies of different building systems utilizing planar finite element models. Consistent, discrete and Boolean design factors are utilized as a part of the setting of sizing, shape and topology optimization. The processed outcomes yield essential building parameters, for example, cross-sectional measurements and properties, area of structural joints, and member layout by means of essence, nonattendance and area of members. The execution and serviceability constraints incorporate typical stress, shear stress, displacement, between story floats, clasping, and natural frequencies. This investigation exhibits the topology optimization method created and utilized for the preparatory design of the bracing system for the hanging façade of another historical center in the United States. The approach utilizes multiobjective Genetic Algorithms to discover a progression of best bargain (Pareto optimal) solutions. The estimation of this method lies in its adaptability to give solutions, enabling the designers to choose optimal solutions when constraints change and adjustments to the structural system happen. Since the principle cost of bracing systems lies in the associations, reducing the quantity of bracings required outcomes in critical cost investment funds.

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