T.C.
ERCIYES UNIVERSITY
INSTITUTEOF SCIENCE AND TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

OPTIMIZATION THE NUMBER SIZE AND LOCATION OF TRUSS MEMBERS FOR STRUCTURAL DESIGN PROBLEMS

Prepared by
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Supervisor
Asst. Prof. Dr. Müslüm KILINÇ

M. Sc. Thesis

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Areej Majeed Abood AL-Saedi

SUTABILITY TO THE REGULATIONS AND TO THE THESIS PROPOSAL

This Master of Science Degree thesis entitled: **“Optimization The Number Size and Location of Truss Members for Structural Design Problems”** has been prepared in accordance with the Thesis Proposal and with the Guidelines for Writing Thesis of Erciyes University.

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This work, entitled: **‘‘Optimization The Number Size and Location of Truss Members for Structural Design Problems '',**which has been prepared by **AREEJ MAJEED** and supervised by **Assist.Prof. Dr.Müslüm KILINÇ,** in the major of Civil Engineering of the Institute of Science and Technology of Erciyes University, has been accepted as a Master of Science Degree thesis by our jury whose identifications and endorsements are given below.

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CONFIRMATION

The acceptance of this thesis has been approved by the decision of the Executive Board of the Institute 26/12/2017 and ...../...../2017/ 55-34

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Areej Majeed Abood

December 2017, KAYSERİ

YAPISAL DİZAYN PROBLEMLERİNDE KAFES ELEMANLARIN KONUMU, BOYUTU VE SAYISININ OPTİMİZASYONU

AREEJ MAJEED ABOOD AL-SAEDI

Erciyes Üniversitesi, Fen Bilimleri Enstitüsü
Yüksek Lisans Tezi, Aralık 2017
Tez Danışmanı: Yrd. Doç. Dr. Müslüm KILINÇ

ÖZET

Kafes sistemlerde kesit optimizasyonu ekonomik açıdan çok önemlidir. Ancak seçilecek kafes tipi de yapılacak kesit optimizasyonunda öncelikli konudur. Kafes sisteme gelen her farklı tipte yük için ve bunların en elverişsiz durumu için optimizasyon yapılması çok fazla zaman alır. Bunu her bir kafes tipi için yapmak ise çok daha fazla zaman alacaktır. Optimum kesit dizaynı için çeşitli metotlar mevcuttur. En yaygın olarak evrimsel optimizasyon algoritmaları kullanılmaktadır. Ancak bunlarda kafes sistemdeki değişken parametre olarak tanımladığımız eleman sayısına bağlı olarak hesaplama süresi değişmektedir. Buradaki çalışmada ise en hızlı şekilde kafes tipi belirlemek için tekrarlı bir metot kullanılarak önce sistem izin verilir emniyet gerilmesine göre kesit dizaynı yapılır sonra da izin verilebilir maksimum yer değiştirmeye göre tüm sistemin kesitleri yarılama metodu ile yeniden hesaplanır. Bu çalışmayla en uygun kafes tipini seçmek çok daha kısa süre de mümkün olmaktadır. Kesit tipi seçildikten sonra burada bulunan değerler kullanılacak optimizasyon için başlangıç ve sınır değerleri olarak alınarak bir hibrit model oluşturulabilir. Bu çalışmada evrimsel algoritmalardan genetik algoritma tekrarlı metotla birleştirilerek kafes sistemlerin konumu, boyutu ve sayısının optimize edilmesi için bir hibrit model geliştirilmiştir. Literatürdeki benzer düzlemsel ve uzay kafes sistem örneklere uygulanıp sonuçlar karşılaştırılmıştır.

Anahtar Kelimeler: Optimizasyon, Kafes Sistemler, Genetik Algoritma

OPTIMIZATION THE NUMBER SIZE AND LOCATION OF TRUSS MEMBERS FOR STRUCTURAL DESIGN PROBLEMS

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ABSTRACT

In truss systems, optimization of the cross section is crucial from an economical point of view. But, selection of best suitable truss type is more important for building an economical truss structure. Apart from that, optimization of a truss structure takes considerable amount of computational time depends on each different type of load combination and the degree of freedom of a truss structure. There are many types of optimization techniques such as genetic algorithm, particle swarm optimization, ant colony optimization etc. available to minimize the cross sectional design. And among those methods evolutionary optimization algorithms are the most commonly used ones. However, the number of elements defined as variable parameters in the truss system affects the calculation time. In this study, an iterative method is used as the fastest way to determine the type of truss. First, the cross sectional area of each member on the structure is designed according to the allowed maximum tensile and compressive strength. Then, considering the maximum allowable displacement, the cross sectional area of each member are updated by using the bisection method. This study contributes to make decision of truss type with a less computational time. After selection of truss type, it can be created a hybrid method by using the initial values and boundary conditions obtained from the iterative method for an evolutionary algorithm. This study proposes a hybrid method with combining a genetic algorithm as an evolutionary algorithm and iterative method to optimize the number, size and location of a truss structures. The proposed method is applied and compared with benchmark planar and space truss structures problems in the literature.

Key Words: Optimization, Truss Structures, Genetic Algorithm

CONTENTS

OPTIMIZATION THE NUMBER SIZE AND LOCATION OF TRUSS MEMBERS FOR STRUCTURAL DESIGN PROBLEMS

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	**Descriptionunits**
A_i	Cross section area for each member
f_i	Internal force for each member
g	Gravitational acceleration
i	Movement of a firefly
ϵ_i^t	Vector of random numbers
r	Distance
t	Time
y(x)	Cycloid curve lies between points A and B.
y`	Derivation of y(x)
β	Variation of attractiveness
β_0	Attractiveness at r = 0
σ_{allow}	Allowable stress

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CHAPTER 1

GENERAL INFORMATION ABOUT THE THESIS TOPIC

1.1. Introduction

This research establishes the procedure for optimizing the topology, size, and shape for plane and space truss structure systems and uses the MAT-LAB software to carry out the genetic algorithm (GA) and finite element analysis (FEA) [1]. This was done for fitness function evaluation. There has been much previous research dedicated to optimizing truss structures and most have focused on the shape of truss members and size of cross sections. Structural design of truss structures falls under the engineering umbrella that covers the structural members [2]. They are distinguished as either truss or frame components that are connected with either pinned or fixed joints.

Costs of materials is among the most considered elements of reducing truss structural weight [3]. There is a wide array of algorithms used by researchers for this task. They include: graphic static [4], intelligent swarm [5], firefly [6], evolution strategy [7], adaptive multi-population differential evolution [8], big bang-big crunch hybrid [9], acultural [1], and the henetic algorithms [1]. All of these methods are meant to decrease truss structure weight with a given variable under the constraints of stress and displacement [3]. Structural optimization is classified as minimizing the mass with optional stress and displacement using the soft constraints of stress and displacement [2]. Optimization is meant to make structures that are ligher, strong, and cheaper. Optimization not only works to improve mechanical properties but to find a global optimization of weight, resistance, rigidity, and cost [2] [8].

Genetic algorithms (GA) is among the evolutionary computation methods and is used by researchers through various optimization schemes for all sorts of systems [3]. It is effective and among the best known of the evolutionary concepts [11]. The GA technique is trial and error and depends upon random actions based on survival of the fittest [2]. Researching using GA look for new methods for optimization and how they use the algorithm produces innovative results every time [2].

There are three perspectives to truss optimization: topology, shape, and cross section area for truss members. Topology deals with selecting nodes and connectivity. Shape optimization covers optimizing the coordinates of existing nodes. Optimizing the cross-section area for node members is also known as size optimization. For each method, the constraints of nodal displacement and stress are considered [7]. These techniques all aim to minimize the weight, which in turn reduces the cost [7].

Genetic algorithms are used to find the best design and solution for plane and space trusses because they require less mathematical effort. This because GA begins with a solution population with a specific scope of searching. This contrasts how other methods are done, as they begin from a single point [3]. The software used for GA is user-friendly and powerful. Because of this simplicity, engineers and designers are easier guided toward optimization. When the software is combined with structure design, there are unusually optimal designs produced [2].

1.2. General Information about Trusses

Truss structures have many individual straight components that connect to the structure at joints. These connections must allow rotation, and therefore there are many considerations of equilibrium in their construction. Each structural member must act as a bar, meaning that they must only carry axial force for tension and compression. Most of the time, these joints do not allow for free rotation. As such, most of these structures are built through estimation. That said, it is imperative that a truss structure allows the individual members to act as bars that support only an axial force. Because of this simplification, it is possible to build these structures using simple math, which allowed for their widespread use in bridges, towers, and other buildings through the 12th Century. Using either rigid or semi-rigid joints, truss structures could also be used for roofs, bridge girders, and steel cargo holders. With rigid joints, the members must be able to bend. This can easily be accounted for through simple calculations. There are many equations for determining the equilibrium of the truss bars and joints. The easiest of these calculations isolates each joint and equates accordingly. Because of each joint's hinge properties, there are two necessary calculations for each joint on a planar truss and three for a space truss. Each of the joints are considered in their sequence. It is also possible to calculate the bar forces by sectioning off the truss into larger divides and applying the necessary equation for each part. Trusses are designed to allow for easy calculation, with the bar forces being determined in a sequential manner [12].

1.3. Basicprinciples

Fig. 1.1 shows the truss structure as it is made of joints that connect to bars. Each joint is numbered 1-7 and each bar is illustrated with a circle. Each joint acts a hinge and allows for rotation around the joint. Forces only impact the truss at each joint. As such, the bars can only support axial forces, as illustrated in Fig. 1.2. There cannot be movement at the ends of each bar because of the hinges. Also, if the force *N* were not properly aligned with the bar's direction, a non-zero moment would occur at the hinge at the opposite end of the bar. Because of this alignment, a bar can only support force with that is aligned with the bar. The force is only positive when it corresponds to tension. With compression, the force is negative.

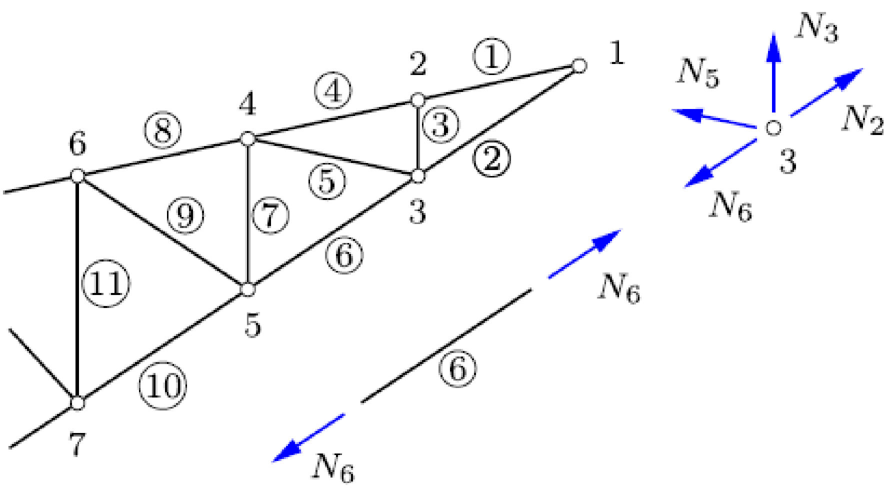


Figure 1.1. Plane truss with joints and bars

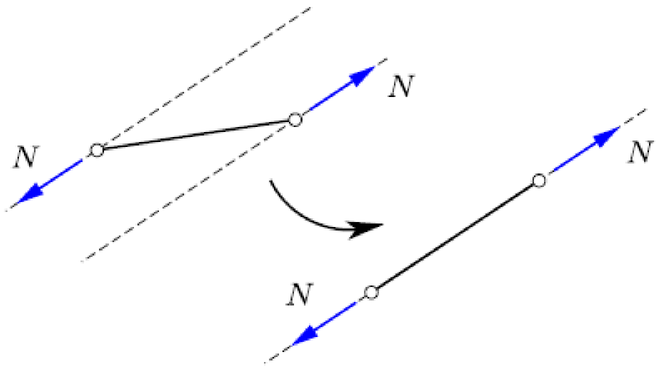


Figure 1.2. Force in a bar along the bar axis

Within the truss structure, sections allow for careful analysis. Sections represent hypothetical separations within the structure, as in separating one component from another. This allows for elaborate calculations of all forces exchanged between both ends. This is illustrated in Fig. 1.1. In the figure, bar 6 is separated from the truss by a section at both ends, near the joints. Force is applied along the bar axis, allowing for symmetry. This means that the force at either end must be of equal magnitude. Magnitude is referred to by $N6$ in the figure. It is positive as it relates to tension. In the figure, one can also read how separating joint 3 can affect the structure. Force from opposite ends of the connected bars allows the structure to preserve its balance. Because of tension, the force within the bar is positive. These forces are shown as $N2$ and $N3$.

The forces $N5$and $N6$ are positioned to point away from the joint. It should be stated that when a tension force of $N6$ is applied to bar 6, the bar will have an $N6$ magnitude that moves away from the bar to the joint that it is connected to. As such, the joints will have an $N6$ force moving towards the node. Positive forces will always point away from a joint or bar from the direction that they are received. On sketches of these truss components, forces are shown as tension, in their positive direction. For compression, the bar force will show a negative value in the magnitude of N. Still, the arrows in the drawings will relate to the direction of tension[12].

1.4. Definition of a truss

In a simple truss, the members receive axial force from either:

1. Compression

2. Tension

Trusses are triangular and composed of straight components that connect at various points this is illustrated in Fig. 1.3. Because of their shape, they are often called web girders. Each of the interconnected components are fastened at nodes that are usually nominally pinned. External forces and system reactions usually occur at these nodes. When members and all corresponding force is along the same plane, these structures are called 2D trusses, or simply planes. The force that is applied is either tension or compression[13].

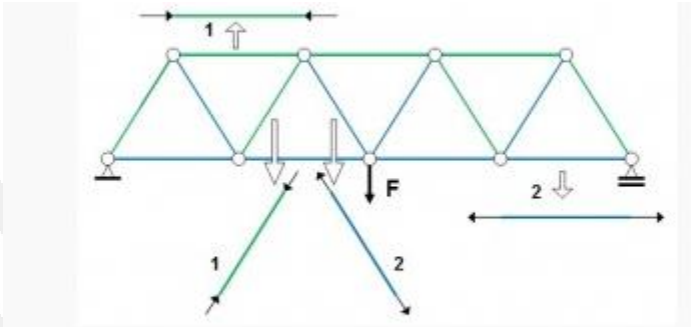


Figure 1.3. Definition of truss

1.5. Importance of Trusses in Construction

Engineers have made vast improvements to their building projects and strategies over the years. Even still, when these ambitious projects came to the building phase, there was significant difficulty because of pressure on materials that were not able to hold large weight. These difficulties birthed the truss system. These web-like structures can hold large amounts of weight and allow for more detailed and intricate building of tall structures, bridges, and more. These trusses not only allow for building extensions, but also for detailed and unique shapes on these buildings[14].

1.6. Materials

The most common material in today’s trusses is lumber. Machines test the wood using stress-rating and then issue a quality grade. This grade is required by several governments, including Canada. Beyond wood, metal plates (galvanized steel) are also used in truss structures. These plates secure the wood at joints and transfer stress from the lumber beans to these joints. This system makes the trusses more bearable to weight[14].

1.7. Uses of Trusses

Truss structures are triangular and are made up of many connected components. Trusses are most often used to support roofing, flooring, and ceilings when constructing buildings. The main uses of trusses are:

- The support of heavy loads
- Their lightweight nature
- Reduction of deflection when compared to each individual part
- And their long lifespan

Engineers can use trusses to make large open spaces with few materials when building. By using less materials, contractors can build at a more cost-efficient rate. Trusses have spaces that also allow for the easy access of piping and wiring through ceilings during construction. Although the purpose remains the same, there are a wide variety of truss designs that are available to engineers. This fluidity gives them the option to make more intricate structures, such as vaulted ceilings. Trusses are prevalent when building bridges and buildings because of their strength. Wooden trusses can also be suited with concrete to increase their strength. Trusses are also used for a wide variety of building structures when engineers must design lengthy areas, such as with aircraft hangers, airports, arenas, and sport stadiums. Because trusses can bear heavy weights, they are also used as transfer structures. The main purpose of trusses breaks down into two:

- Carrying roof loads
- Horizontal stability when building[13][14]

1.8. Types of Trusses

There are many different types of trusses, the most common being: triangular, Howe, and Fink, as shown in Figures 1.4, 1.6, and 1.9. These types are simple and do not exceed 10 feet in length. Inverted trusses are more complex. They are shaped in obtuse triangular patterns and are used for curved or segmented ceilings. Attic trusses are common for home attics and they allow for space in the center, typically used for storage (shown by Figure 1.10). A more complex design is the half-scissor truss that creates a flat, vaulted ceiling. Other types of trusses include [13]:

- Pratt (N truss)
- Warren (Figures 1.8)
- North-light
- Saw-tooth (butterfly)
- Fink

The types of trusses used for bridges are [15]:

- Pratt
- Howe
- K (Figure 1.7)
- Warren

Roof trusses include [16]:

- King post
- Queen post
- Pratt
- Howe
- Fan
- North light
- Scissor
- Raised heel
- Quadrangular
- Parallel chord

Figure 1. 4. Triangular truss in USA,

Figure 1.5. Pratt bridge truss in USA

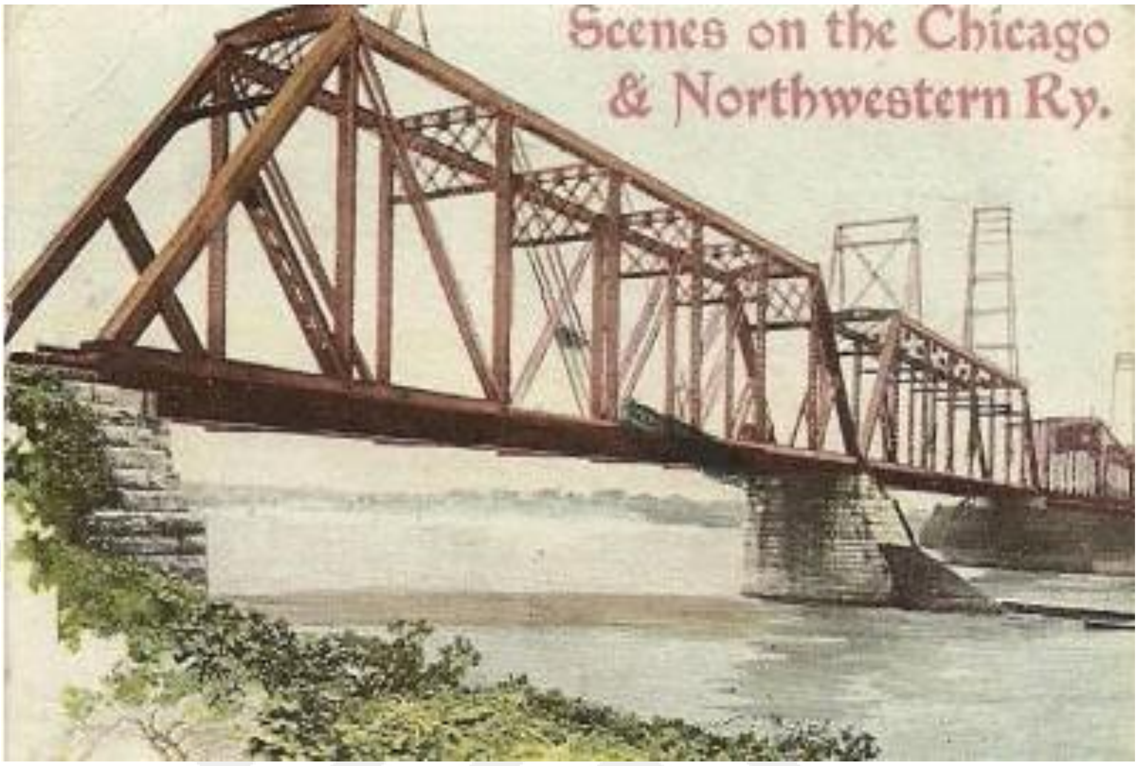


Figure 1. 6. Howe bridge truss in Clinton County, Iowa chicago

Figure 1. 7. K- bridge truss in USA

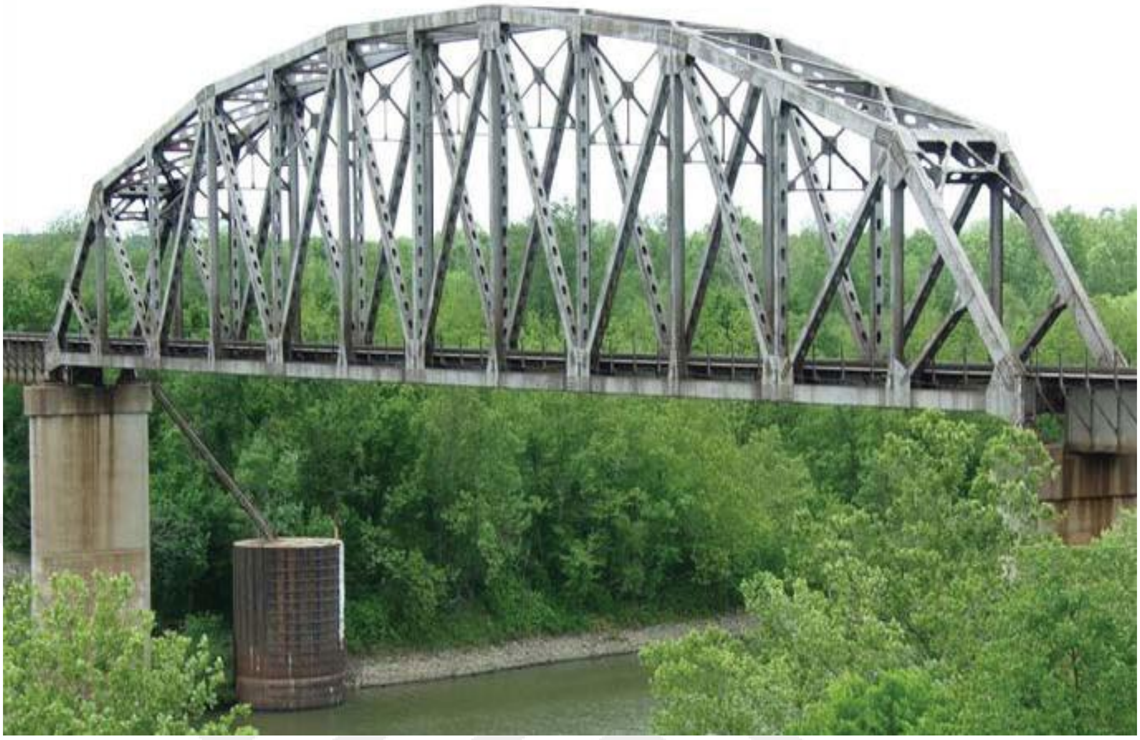


Figure 1.8. Warren, Isometric, Truss, Polygonal top chord, with verticals, all riveted steel bridge for BNSF Railroad over Verdigris River, Oklahoma~1960.

Figure 1. 9. Fink truss bridge in San Antonio(USA)

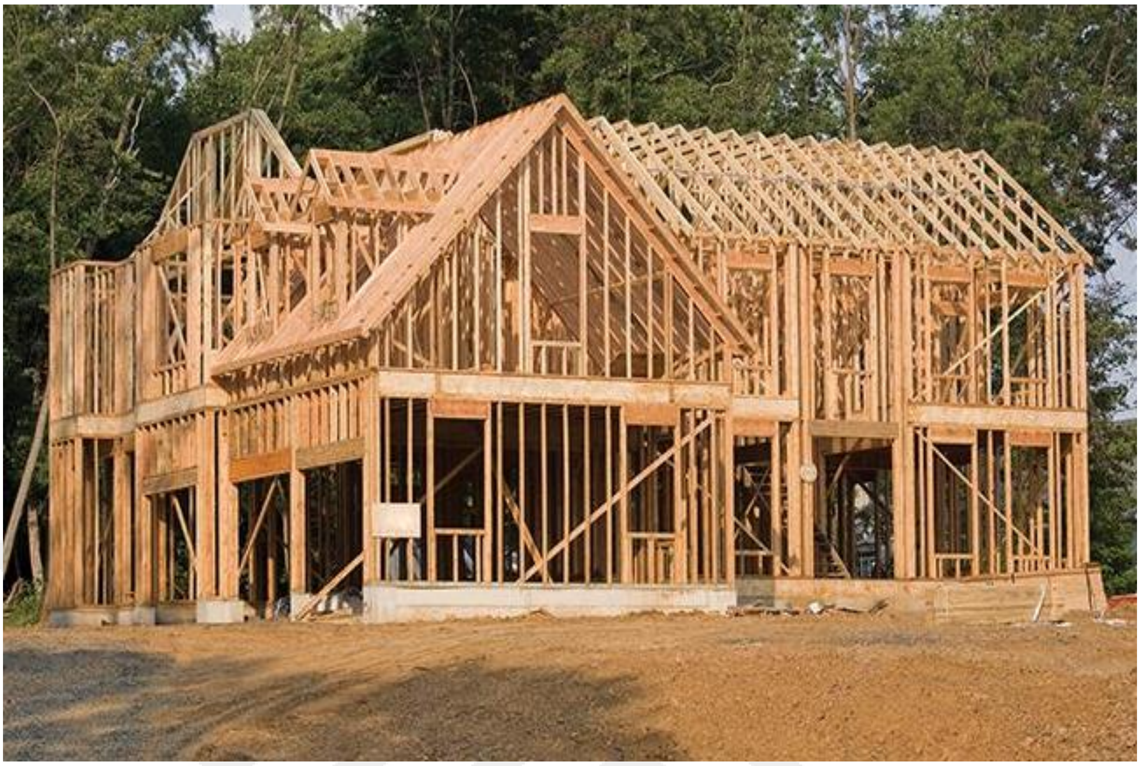


Figure 1. 10. Attic Truss Roof in USA

1.9. Literature review

It is important that plane and space truss structures use genetic algorithms (GA) for weight optimization. This makes them both more economical and sustainable. Many researchers have used optimization with regards to sizing, topology, and geometry optimization. A lot of research focuses on applications that use traditional design variables that contain the node coordinate elements of connectivity and cross sections. This research presents a method for optimum space and plane truss design using the genetic algorithm and build around the constraints of displacement, stress, and buckling [3].

The first studied research was that of Osman Shallan, AtefEraky, TharwatSakr, and Osman Hamdy [3]. Their study was based on optimizing plane and space trusses through genetic algorithm. They reduced the chromosome length without affecting the GA efficiency. One of their proposed methods was the use of nodal deflections instead of member sections, and using nodal coordinates. This method reduces the genotype length because nodes are less than members in trusses and because the range of nodal displacement is lower than the steel sections that are available on truss members. It is also possible to predict the direction of deflection for loads and configurations, which can reduce deflection variable by 50 percent and improve calculations. Using this simple condition, it is also possible to remove and keep members and this makes it possible to optimize topology without using chromosomes. It also allows for less complex design and the ease of solving problems when compared to the traditional methodology. This is because the topology optimization depends on the variables of node deflections and coordinates. The results of this study provide a more optimal weight, a reduction in calculation time, less effort because of less numbers, and the choosing of sections from large numbers from a defined set without increasing the length of the chromosome.

The next study used in this research was conducted by Hossein Lotfi and Ali Ghoddosain [9]. For optimizing the size and shape of two-dimensional truss structures, the researchers used the Hybrid Big Bang-Big Crunch (HBB-BC) algorithm. Using HBB-BC, they made minor changes and provided solutions to three design examples as they relate to the size and shape of 2D trusses. Their changes optimized the HBB-BC algorithm through the particle swarm algorithm, which finds and implements the time range by making finite sub-domains. Their goal was to find the optimum truss structure weight, node features, and element cross-section size while meeting the demands of tension strain and nodal deflection while retaining the given design variable limit. The results were clear in showing that the HBB-BC algorithm was better for solving 2D trusses than the compared algorithms. The research explained a problem of decreasing the domain coefficient and the process use time of a 10-bar truss with a lesser method of optimization. They solved this issue in different cases so that the required number of random variables and best repetitions could be extracted. It was easier to solve these issues with the obtained coefficients instead of through other means. The researchers outperformed their benchmark tests on this issue. Another issue highlighted by the research was with a 15-bar truss. On the first truss, they solved the problem using the same elements quicker than their benchmark, while considering each element separately. The researcher also examined an 18-bar truss that was optimized with the HBB-BC algorithm for better results than other methods on their benchmark test. This study was the first to use the HBB-BC algorithm for size and shape optimization of 2D trusses and provided excellent results in shorter times while solving each of the mentions problems. This shows that the HBB-BC algorithm is better than similar heuristic algorithms and can be used across many fields for structural optimization.

The next research was conducted by Leandro Fleck Fadel Miguel, Rafael Holdrof Lopez, and Leticia Fleck Fadel Miguel [6]. This study uses the firefly algorithm (FA) to optimize the size, shape, and topology of truss structures. The goal was to minimize the structural weight while keeping the constraints of displacement stress and kinematic stability. The firefly algorithm was more efficient at optimization compared to other methods mentioned in this writing and had lower costs. This alludes to the potential for a widespread application of this method. This procedure provides near-optimal results in each test that showcase various optimized designs. The firefly algorithm was used to optimize the size, shape, and topology of truss structures in a single stage. This study shows that this method is suitable for solving various optimization issues.The firefly algorithm uses one stage for multimodal optimization and provides multiple solutions at the end of each test. This is a sought-after solution because it is not always possible to account for aspects of constructions or aesthetic concerns. Using multimodal optimization, the engineer can assess these considerations through the external requirements. The FA solution for optimizing truss size, shape, and topology that provides better or equal results to the other methods mentioned at lower costs provides a general solution to many of the common application problems.

The study performed by Dominique Chamoret, Kepend Qui, and MatthieuDomaszewski [8] uses the Probabilistic Global Search Lausanne (PGSL) method for optimizing truss structure design. This original stochastic method was developed at the Swiss Federal Institute of Technology at Lausanne, hence the name. The researchers fitted it with a finite element code and tested it to solve size problems for plane truss structures. PGSL uses a probability distribution function (PDF) and samples the search space to locate the best structure. Using the PDF, researchers can find the best solution at any point during their search. The PDF focuses on finding solutions where other good solutions exist, and therefore increases the probability of finding a solution that works. This method avoids the sensitivity analysis to find the global optimum. The PGSL system searches for alternative algorithms for optimization at faster speeds with less function evaluations. This can drastically improve the performance of computations. The researchers tested the PGSL method on many simple problems for structural optimization.

1.10. The Main Idea - Why Trusses Need Optimization

J.E. Gordon defines a *structure* in mechanics as: “any assemblage of materials which is intended to sustain loads.” The term *optimization* refers to making anything the best it can possibly be. As such, *structural optimization* means improving any combination of materials so that loads are best sustained. Fig.1.11 provides a basic example of why optimization is important. In this figure, a load should be moved onto a fixed support and this must be done in the best possible way. As far as engineering is concerned, what does “best” mean? It could either mean making the structure as light as possible, as stiff as possible, or making it stable so that it is impervious to buckling. With building, there are obvious constraints that must be considered before embarking on such a task. For example, without a limit of used materials, one can make the structure stiff to an undefined limit, which presents a serious problem. The various constraints that are present in building are typically: the geometry of the structure, stresses involved, and the displacement of these stresses. When using such constraints, a clearer image of what is “best” begins to emerge, including the structures objective function. As such, the measures on structural performance can be defined by geometry, weight, critical load, stiffness, displacement, and stress. With structural optimization, one of these factors is considered and either maximized or minimized to meet the needs and intended purpose [17].

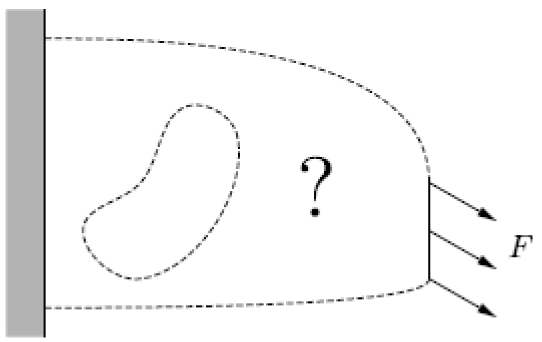


Figure 1.11. Structural optimization problem. Find the structure which best transmits the load F to the support.

1.11. Optimization Techniques

There are several optimization techniques. These can be separated into two broad ideas: function and parameter. For optimization through function, the considered object is defined by various undefined functions. These functions are discovered through the process of optimizing. Differential calculus is used to discover the optimum function. A common optimization problem, posed by Johann Bernoulli in 1696, is the brachistochrone problem. Under the brachistochrone problem, one finds the plane curve that connects to the two given points of A and B, to allow a bead to slide between the two at a minimum time, using gravity. The term derives from two Greek words: *brachistos* which means “shortest” and *chronos* which means “time.” This problem is solved with a cycloid curve of y(x) that lies between points A and B. It minimizes the integral as shown in the following equation (1.1),y`where is the derivation of y(x) and g is the gravitational acceleration:

$$t = \int_A^B \sqrt{\frac{1 + \left(y'\right)^2}{2gy}}\ dx \qquad Equation\ (\ 1.1\ \ )$$

With parameter optimization, the optimum values of each design variable are determined for specific problems, instead of searching for a general optimum function. Parameter optimization techniques include: optimality criteria (OC), mathematical programming, and metaheuristic methods[18]. These techniques can be broken down further into three categories: sizing, configuration, and topology optimization.

- **Sizing**: Here, the cross-sections of each members are the design variables and the node coordinates and member connections are fixed. This presents a nonlinear programming problem (NLP). Sizing optimization restricts cross-sections to only pre-defined discrete values.
- **Configuration**: Here, the nodal coordinates are the design variables. Sizing and configuration is often used in conjunction. There is also an NLP problem with regards to the member are and changes in the nodal coordinates.

- **Topology**: This refers to the determination of member connections within a truss. There is not enough information regarding this technique because there are inadequate methods to show member connectivity[19].

CHAPTER 2

2.1. Designing Truss Structures

In order to design a truss structure, it is important to follow specific criteria, the most important of which is that it must support safe load carrying. The type of truss structure should be chosen according to the load conditions. Truss structures are characterized by their node numbers and members. The truss structure is analyzed once the support and load conditions are established. Using structural analysis, the internal force and overall strength of each component is determined. The cross sections are first assumed as random values to start. Once the analysis is completed, the strength of each material is updated in the data. However, for some truss structures, inspecting allowable stress is not enough and maximum displacement of each node must be found. Each component of the compressive bar should be checked for buckling in some truss systems. This is because truss design is based on each component's allowable strength, the node's allowable displacement, and the buckling control for each component of the compressive bar.

2.2. Truss Structure Optimization Methodology

2.2.1. Iterative Methods

There are two solutions for iterative methodology: direct and indirect. For the direct, or determinate, way, stress and displacement are checked because the internal force is permanent. In the indirect, or indeterminate, way, iterations are repeated until the best solution is found.

The total iterative process could be outlined as:

1. Planning: First, the structure's functions must be established and measurement criteria must be set to gauge whether the design is optimal.
2. The components that serve the planning phase are then arranged.
3. The loads that must be carried are set.
4. Once the first three steps are finished, the components that suit the design criteria are selected and considered for structural weight and overall cost.
5. Analysis: Structural analysis is carried out regarding the loads and framework to find internal forces and wanted deflection.
6. Evaluation: Next, the structure is evaluated as to whether it serves the needs and if the results are the best they can be based on the earlier data.
7. Redesign: If there is any unwanted data found in the design, the above six steps are then repeated. It is more common that steps three through six are repeated because the initial data serves the overall purpose.
8. Final: Here, it is determined whether or not the best overall design was found[20].

2.2.2. Stochastic Optimization

This methodology represents ways to minimize or maximize a specific objection function under random conditions. These techniques are incredibly useful to the statistics, computer science, science, and engineering industries. There are varying degrees to these applications, they can however include: simulating the best placement for acoustic sensors along a beam, releasing water at the best time within a reservoir, and perfecting a set of data based on specific parameters. The problem is effected by randomness by either cost of set of constraints. Although randomness may occur at various aspects of design, it is focused on random objective functions or constraints[21].

EXAMPLES

1. Genetic Algorithm (GA)

There are three characteristics to genetic algorithms: selection, crossover, and mutation. At each iteration (generation), these three are applied to various solutions (individuals) for the purpose of improving fitness. Each of the individuals are represented by a string that resemble natural chromosomes. This resemblance is the reason for the name “genetic algorithms.” The population is first randomly produced until a specific criterion is met. These criteria can be a generation limit being passed or a lack of individual improvement. The GA method is widely used because of its ease and accessibility to many applications. It is easily adapted to a wide array of problems, that contrasts other methods that are limited to one type of issue. Beyond its ease, the GA method is quite in-depth and is not hindered by local optimums like other methods. The GA method also handles discrete variables because it uses function evaluations opposed to derivatives. As such, it can be used in complicated search spaces.

Beyond the positives, the GA method also has flaws. It needs quite a number of function evaluations and often experiences premature convergence when individuals are similar. There are also a wide array of options and alternatives, which makes finding the most effective settings difficult [11]. A team led by Cazacu [1] was able to optimize and find the minimum weight of six nodes and 11 bars on a planar steel truss using the GA method. Also, a team led by Shallan [3] optimized a plane and space truss, finding the minimum weight for a 10 bar plane trust and 25 bar space truss.

2. Particle Swarm Optimization (PSO)

This method is inspired by the social behavior of flocks of birds, schools of fish, and insect swarms (shown in Figure 2.1) and is a type of swarm intelligence. It was developed in 1995 by Dr. Eberhart and Dr. Kennedy. When one member of the swarm chooses the optimal path, the other members follow immediately, even if they are far from one another. The swarm also has a level of randomness in it, to facilitate exploration. This means that the swarm is influenced by other members but also has independent exploration capabilities. Each of many particles exist in a multidimensional space and have their own position and velocity. They fly through hyperspace with two rationales: memory of their individual best position and the memory of the swarm’s best position. Here, the term best refers to the position with the smallest objective value. The particles will communicate with each other about these positions and adjust themselves and their velocities to match. This is done in two ways:

- The global best is commonly known among the swarm members and updated upon discovery of new best by any particle
- Neighborhood bests are exclusive communications between a particular group of the swarm about the best position

Each of the particles stores the coordinates for the best solution in a value called *pbest*. There is another best that is tracked between all particles for the best value obtained by any swarm member called the *lbest*. The global best, or *gbest*, is the best among all particle members in conjunction.

At each step in the PSO, the velocity of each particle is changed according to the *pbest* and *lbest* locations. Individual random values are made for acceleration toward the *pbest* and *lbest* positions to weigh the overall acceleration. PSO is similar to Genetic Algorithms and other evolutionary calculation methodologies in many ways. Still, it varies from GA because there are no evolution operators like mutation and crossover.

Particles in PSO are optimized by following the particle with the current best value. This method has grown quite a bit in recent years, with a broad range of application and research devoted to it. PSO has proven more accurate results than other methods, with less costs and faster speeds. PSO is also preferred because of minimal parameters that need adjusting, and it is possible to use the same version one across many applications[22]. Researchers Perez and Behdinan [23] used PSO to get the minimum weigh for 10 bar, 25 bar, and 72 bar space trusses.

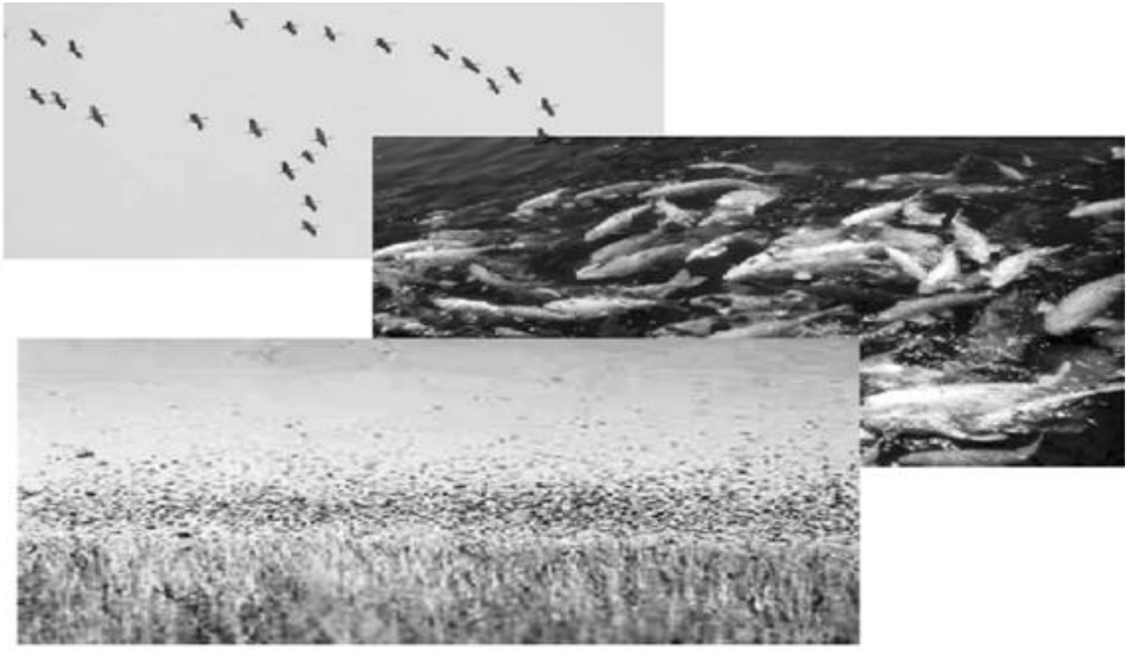


Figure 2.1. Social behavior

3. Firefly Algorithm (FA)

This method was developed at Cambridge University by Xin-She Yang between 2007 and 2008. Yang was inspired by fireflies, in terms of their flashing lights and general behavior. It has seen a boom in recent years, with hundreds of research papers dedicated to these algorithms. The FA method is broken down into these three rules:

1. The unisex nature of fireflies in that they are attracted to one another irrespective of sex.
2. As such, the fireflies' attractiveness comes from its brightness. Less bright fireflies will gravitate towards brighter ones. In the absence of a distinction of brightness, fireflies move in a random fashion.
3. Firefly brightness is dependent on an objective function and the beauty is in proportion to intensity of light that is seen by others. As such, the equation for attractiveness (β) is defined by:

$$\beta = \beta_0 e^{-\gamma r^2}, \tag{2.1}$$

where β_0 is the attractiveness at $r = 0$.

The movement of a firefly $i$is attracted to another more attractive (brighter) firefly

$$x_i^{t+1} = x_i^t + \beta_0\ e^{-\gamma r^2}ij\ (x_j^t - x_i^t)\ \ + \alpha_t \epsilon_i^t\ , \tag{2.2}$$

The second term is caused by attraction. The third represents randomness with its parameter represented by α_t and the randomness vector being drawn from a uniform set time (t) by ϵ_i^t. A simple random set is true when $\beta_0 = 0$. Swarm particle optimization is reduced by FA if $\gamma = 0$. The randomness (ϵ_i^t) can be extended to other distributions including the Levy flights [24]. The method was used by a research team led by Miguel [6] and they obtained the minimum weight for an 11 bar planar trust, 29 bar two-tiered truss, 25 bar 3D truss, and 15 bar planar truss.

2.2.3. Finite Search

All possible alternate solutions are searched for using this method in order to locate the best one. The function must be discrete to use this technique. Although the objective function is most often defined as continuous when optimizing trusses, it is often a better option to use the discrete objective function. Because there are an infinite number of alternates in continuous functions, it becomes impossible to use all the possibilities. For real applications, truss structure bar elements are made with specific cross-sections. They can also be made according to any needed size, but this process is more expensive. Because of these issues, truss optimization works better with a defined objective function. All design options can be tested with the finite search method in order to locate the best solution. That said, this method can have expensive computational costs for certain sizes, member numbers, and node numbers.

CHAPTER 3

ANALYZING STRESS AND DISPLACEMENT FOR PLANE TRUSSES USING (ITERATIVE, OPTIMIZATION, HYBRID) METHODS

3.1. Iterative Method

Using this method, the limitations of stress and displacement are tested for a planar truss structure, as shown in Figures 3.1 and 3.2. The weight is checked for the first. The stress is checked for the second and it must be lower than or equal to the allowable stress and displacement. There are two structure types: deterministic and indeterministic. For deterministic, the system internal forces don't depend on its geometry or material properties. As such, if internal forces are found once, then the cross areas can be found using allowable stress. It is not needed to apply iterative methods to find displacement, as both systems are increased by a given percentage. This is true for every component. This is because structure stiffness does not change at each component.

f_i: Internal forces for each member

σ_{allow}: allowable stress

A_i: Cross section area for each member

A_i: f_i / σ_{allow}

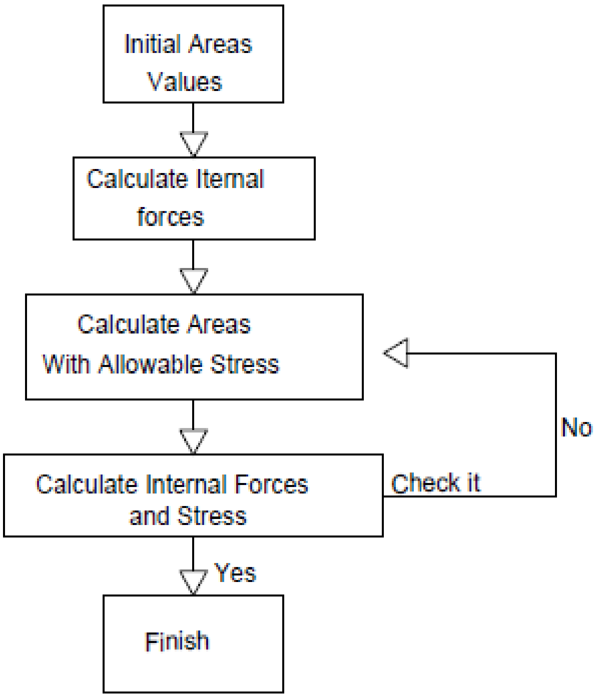


Figure 3.1. Flowchart for stress

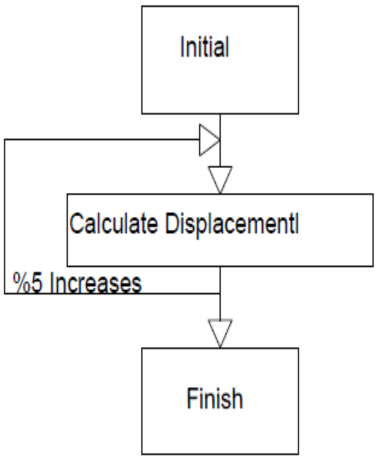


Figure 3.2. Flowchart for displacement

3.2. Optimization Method

Optimization means ensuring things are the best they can be. There are several steps to optimizing truss systems:

1. Function: What purpose does the product serve? When pondering bridge design, one should ask how long it should be, what expected loads there are, and how many driving lanes are needed, among other questions.

2. Concept: What conceptual design process should be used? For instance, does the bridge need to be a truss, suspension, or arch bridge?
3. Optimization: Based on the concept, function, and the respective constraints, this means to make a product that is as best as possible. Again, dealing with bridges, this could also mean reducing cost wherever possible and using the least amount of materials.
4. Details: This step is based on the market, or social and esthetic influences. For bridges, it may mean the overall color scheme (so that it is pleasing to the eye and fits the surrounding area).

The most commonplace method for fulfilling step 3 is iterative-intuitive. This is broken down as:

1. Suggestion of design
2. Investigation of required functions
3. If functions go unfulfilled, then a new design is presented
4. Then repeat steps with new design

When fashioning mechanical structures, Step 2 mentioned above is performed using computer software with the Finite Element Method (FEM) and Multi Body Dynamics (MBD). Software enables that design functions are better analyzed and therefore, every step becomes easier. That said, software does not drive forward the need for changing the strategy. The computer program will formulate a mathematical optimization problem to find the best overall function set, using precision. As such, this method is automatic when compared to the iterative-intuitive method. This research covers mathematical optimization in that structures are studied who have one major task: carry loads. The subset of this research is deemed structural optimization. Although this method is useful, not every factor is successfully considered using mathematical design. In order to fully optimize such structures, they must be mathematically measurable. Of course, mechanical factors are easily covered with mathematics. However, esthetic features are difficult to factor using this method. The genetic algorithm (GA) is used in this study, because the vast number of variables making mathematic solving very difficult [17].

3.3. Hybrid method

The hybrid method's concept is simple. For a particular calculation problem, there are two algorithms: recursive (A1) and another (A2) that is often iterative. (A1) is asymptotically quicker, so that it has higher constants in running time than (A2). A recursive algorithm (H) can be created when (A1)'s code is modified, such as: introducing a new value for the instance size (n_0), then it is solved using (A2). The rest of the code remains the same, except for recursive substitutions into (H). As such, (H)'s code is:

H(i)

if size(i) $\leq n_0$

then return A_2(i)

* DIVIDE step of A_1 *

* RECURSE step of A_1 (but using H for the calls)*

* CONQUER step of A_1 *

The purpose of crafting (H) is finding the best solution for both algorithms, such as keeping the asymptotic behavior from (A1) and lowering constants because (A2) uses smaller instances. It deserves mention that in the above code, the switching port (n_0) is a value that must be found and fixed within the analysis in order to minimize the hybrid algorithm's running time[25]. So, the hybrid algorithm is:

1. Combining more than one algorithm to effectively solve the problem.
2. Combining two or more algorithms for better performance.
3. Each of the algorithms has simpler algorithms within.
4. Two or more algorithms that solve the same problem are used in conjunction, and either the simpler one is used or they are alternated depending on the situation. This is so that each algorithms' qualities are maintained. It is important to note that the hybrid algorithm does not combine multiple algorithms to solve different problems, but rather multiple algorithms that are simpler pieces of the larger algorithm's problem. Each of these algorithms are different in terms of their characteristics, most notably as it relates to performance.

This research combines two methods for a better solving of the best solution for planar truss structures in terms of minimal weight. This is done with the genetic algorithm and iterative method [26].

3.4. Finite Search Method

This method has two parameters in the vertical: the diagonal and the horizontal, or AI and A2. This method is run $400^2$to find the results. In the figure, the brown side is not safe for structures and the blue if the parameters' minimum weight. The best solution is along the border of the unsafe part. An optimization difficulty is that the structure has no smooth surfaces.

3.5. Iterative, optimization, Hybrid methods for planar trusses Condition (1)

3.5.1. (10) bar planar truss (indeterminate system) (case1)

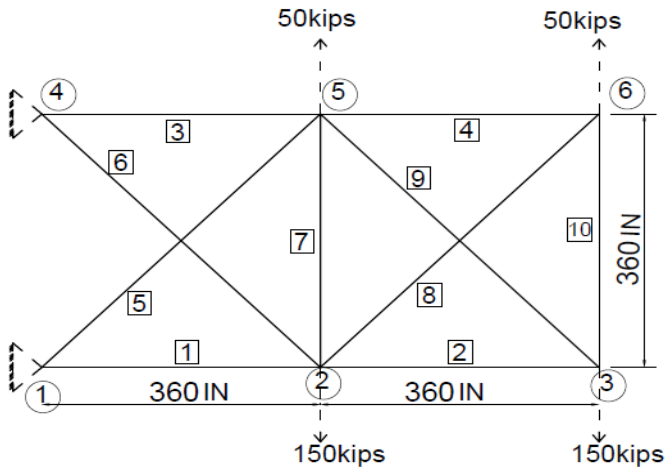


Figure 3.3. (10 bar planar truss)

The (10, 12, 11, 9, 12) bar planar trusses shown in Figures (3.3, 3.4, 3.5, 3.6, 3.7) are the first, second, third, fourth, and fifth design examples. The truss members Young's modulus and material density are 10^4ksi and 0.1 lb/in^3. Each member face stress limits of ±25 ksi and the maximum nodal displacement in the X and Y directions are limited to ±2 in all free nodes. Each members' minimum allowable cross-sectional area is 0.1 in^2. For the design examples (condition 1): node 2 = -150, node 3 = -150, node 5 = 50, node 6 = 50 kips for case 1 through

4. For case 5: node 2 and 3 = -150 and node 6 and 8 = 50. For condition 2, in node three, the load is -200 in all five cases.

This research analyzes each of these trusses by the iterative and hybrid method using the MATLAB software. The stress of each member is then compared to the allowable stress of 25 ksi. At the conclusion, each member was found to satisfy the conditions and to not exceed the allowable stress [10].

Why Case 1 is an Indeterminate System

number of equation =2*number of truss joints=2*6=12

number of unknown forces=number of truss members+number of support reactions

10+4=14

Because the number of equations is not equal to the number of unknown forces, therefore the truss is statically indeterminate system.

Table 3.1.The Result for 10 bar planar truss (Case1)

Elem No.	Iterative Area for stress (in^2)	Iterative Area for displacement (in^2)	Area for optimization (in^2)	Area for hybrid (in^2)
1	10.0093	37.3691	24.5	24.4
2	3.9964	14.9203	16.3	13.7
3	5.9971	22.3901	29.5	23.4
4	0.0100	0.0373	1.3	0
5	2.8221	10.5363	14.9	12.6
6	8.4961	31.7199	12.0	12.8
7	0.0100	0.0373	0.7	0.1
8	0.0100	0.0373	1.4	0.1
9	5.6517	21.1004	19.6	21.3
10	2.0060	7.4894	5.7	2.1

3.5.2. (12) bar planar truss (determinate system) (case2)

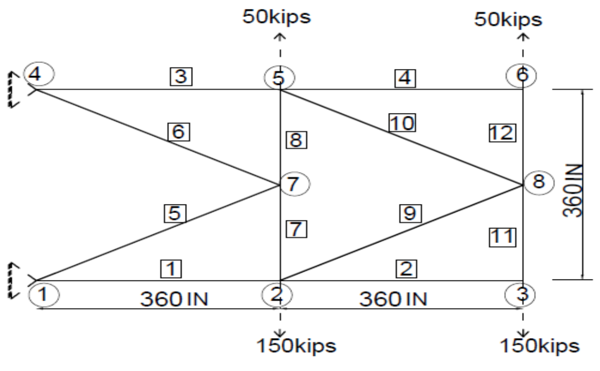


Figure 3.4. (12 bar planar truss)

Fig 3.2.(12 bar planar truss)

Why Case 2 is a Determinate System

number of equation =2*number of truss joints=2*8=16

number of unknown forces=number of truss members+number of support reactions

12+4=16

Because the number of equations is equal to the number of unknown forces, therefore the truss is statically determinate system.

Table 3.2. The result for12 bar planar K truss (Case2)

Elem No.	Iterative Area for stress (in^2)	Iterative Area for displacement (in^2)	Area for optimization (in^2)	Area for hybrid (in^2)
1	4.0016	14.2284	0.0140	0.0161
2	0.0100	0.0356	0.0018	0.0001
3	4.0016	14.2284	0.0174	0.0149
4	0.0100	0.0356	0.0020	0.0001
5	8.9479	31.8156	0.0270	0.0262
6	8.9479	31.8156	0.0268	0.0256
7	8.0032	28.4568	0.0150	0.0192
8	0.0100	0.0356	0.0022	0.0001
9	4.4739	15.9078	0.0189	0.0182
10	4.4739	15.9078	0.0193	0.0187
11	6.0024	21.3426	0.0198	0.0227
12	2.0008	7.1142	0.0080	0.0022

3.5.3. (11) bar planar truss (indeterminate system) (case3)

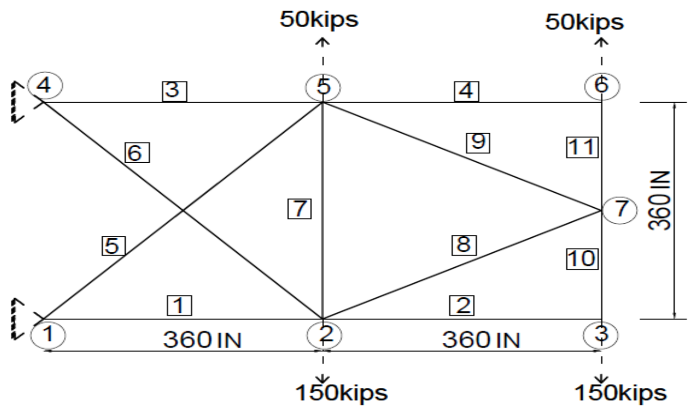


Figure 3.5. (11 bar planar truss)

Table 3.3.The result for11 bar planar truss (Case3)

Elem No.	Iterative Area for stress (in^2)	Iterative Area for displacement (in^2)	Area for optimization (in^2)	Area for hybrid (in^2)
1	11.9981	42.6614	29.3	36.5
2	0.0100	0.0356	4.5	0.1
3	4.0083	14.2521	22.5	16.7
4	0.0100	0.0356	3.8	0.1
5	0.0100	0.0356	3.5	0.1
6	11.3088	40.2104	22.1	30.5
7	0.0100	0.0356	0.3	0.1
8	4.4739	15.9078	24.0	18.9
9	4.4739	15.9078	18.5	18.3
10	6.0024	21.3426	17.0	20.6
11	2.0008	7.1142	3.2	2.4

3.5.4. (9) bar planar truss (indeterminate system) (case4)

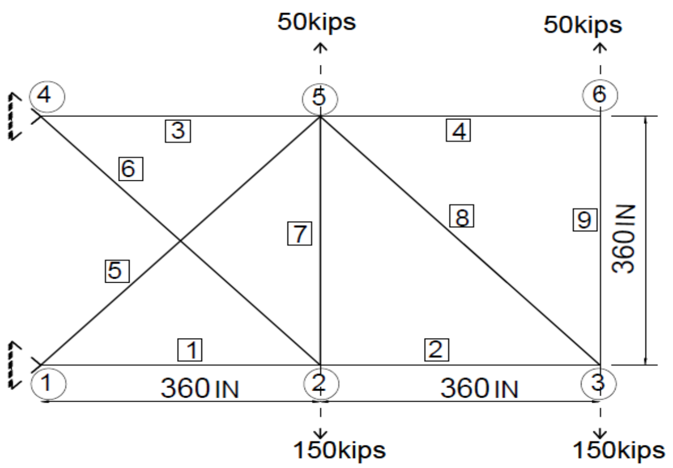


Figure 3. 6. (9 bar planar truss)

Table 3.4.The result for 9 bar planar truss (Case4)

Elem No.	Iterative Area for stress (in^2)	Iterative Area for displacement (in^2)	Area for optimization (in^2)	Area for hybrid (in^2)
1	10.0032	37.3465	22.4	25.3
2	4.0016	14.9398	19.5	15.4
3	6.0032	22.4127	29.2	23.3
4	0.0100	0.0373	0.5	0.1
5	2.8307	10.5682	13.7	11.4
6	8.4876	31.6879	12.2	12.4
7	0.0100	0.0373	0.9	0.1
8	5.6591	21.1281	19.8	21.3
9	2.0008	7.4699	3.1	2.5

3.5.5. (12) bar planar truss (determinate system) (case5)

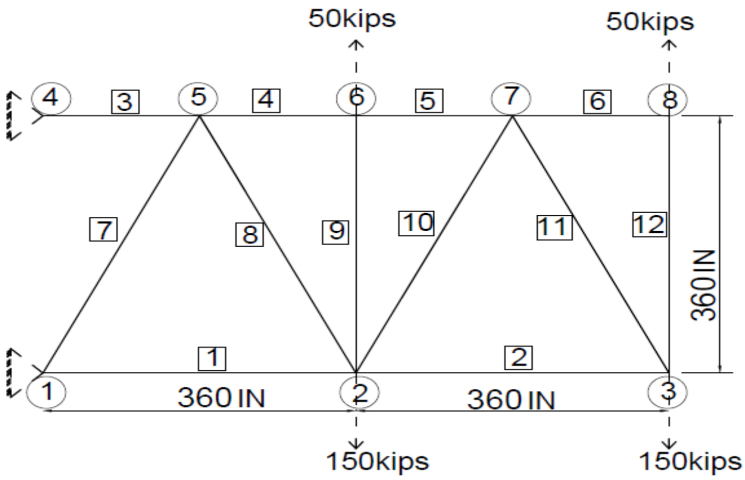


Figure 3.7. (12 bar planar truss)

Table 3. 5.The result for 12 bar planar truss (Case5)

Elem No.	Iterative Area for stress (in^2)	Iterative Area for displacement (in^2)	Area for optimization (in^2)	Area for hybrid (in^2)
1	8.0032	32.9423	31.7	31.3
2	2.0008	8.2356	8.8	8.7
3	12.0048	49.4134	38.4	38.5
4	4.0016	16.4711	19.0	16.8
5	4.0016	16.4711	23.7	19.2
6	0.0100	0.0412	1.4	0.1
7	8.9479	36.8306	26.9	36.4
8	8.9479	36.8306	36.6	31.2
9	2.0008	8.2356	2.1	2.4
10	4.4739	18.4153	24.5	21.2
11	4.4739	18.4153	21.4	21.5
12	2.0008	8.2356	2.3	2.0

Table 3.6. Loading conditions for four case planar truss.

Node	**Condition1(kips)**		**Condition2 (kips)**	
Case1- 4	**Px**	**Py**	**Px**	**Py**
2	0.0	-150	0.0	0.0
3	0.0	-150	0.0	-200
5	0.0	50	0.0	0.0
6	0.0	50	0.0	0.0

Table 3.7.Loading conditions for case five planar truss.

Node	**Condition1 (kips)**		**Condition2 (kips)**	
Case 5	**Px**	**Py**	**Px**	**Py**
2	0.0	-150	0.0	0.0
3	0.0	-150	0.0	-200
6	0.0	50	0.0	0.0
8	0.0	50	0.0	0.0

Table 3.8. The weight for five case for iterative, optimization and hybrid method (condition 1)

Weight (Ib)	**Case1**	**Case2**	**Case3**	**Case4**	**Case5**
Iterative stress	1657.5	1657.6	1657.8	1657.4	1945.0
Iterative displacement	6188.3	5893.8	5894.5	6187.8	8005.7
optimization	5250.9	5784.5	5548.6	5042.5	7503.7
hybrid	4675.1	5489.4	5395.0	4691.3	7383.2

Table 3.9. The weight for five case for iterative, optimization and hybrid method (condition 1,2).

Weight (Ib)	**Case1**	**Case2**	**Case3**	**Case4**	**Case5**
Iterative stress	2554.6	2413.7	2500.3	2577.5	2737.3
Iterative displacement	9537.6	8582.3	8890.1	9623.1	11267
optimization	8868.7	8504.5	8703.4	8803.6	10965
hybrid	8799.1	8365.5	8513.0	8774.8	10740

Conclusion

The best results are Case 1, or the X truss shown in Figure 3.3. This is true for this planar truss because it provides the minimum weight for both iterative and hybrid methods. For the planar truss topology optimization, 43 cases were made in the structure with the best weight shown using the iterative method in Case 2 for the K truss (Figure 3.4). the best weight shown using the optimization method in Case 5 in fig 3.7.Using the finite search method, the best result is shown in Figure 3.8 below.

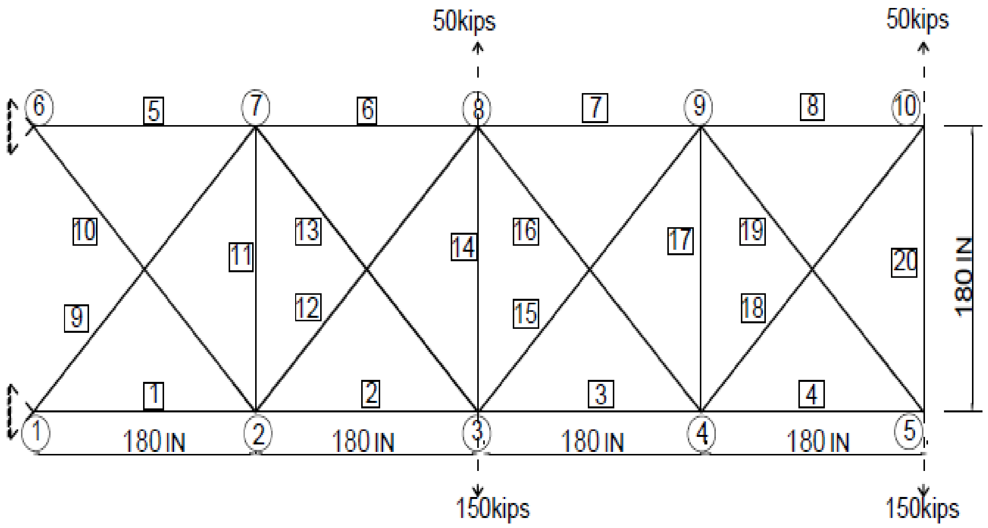


Figure 3. 8. (20 bar planar truss)

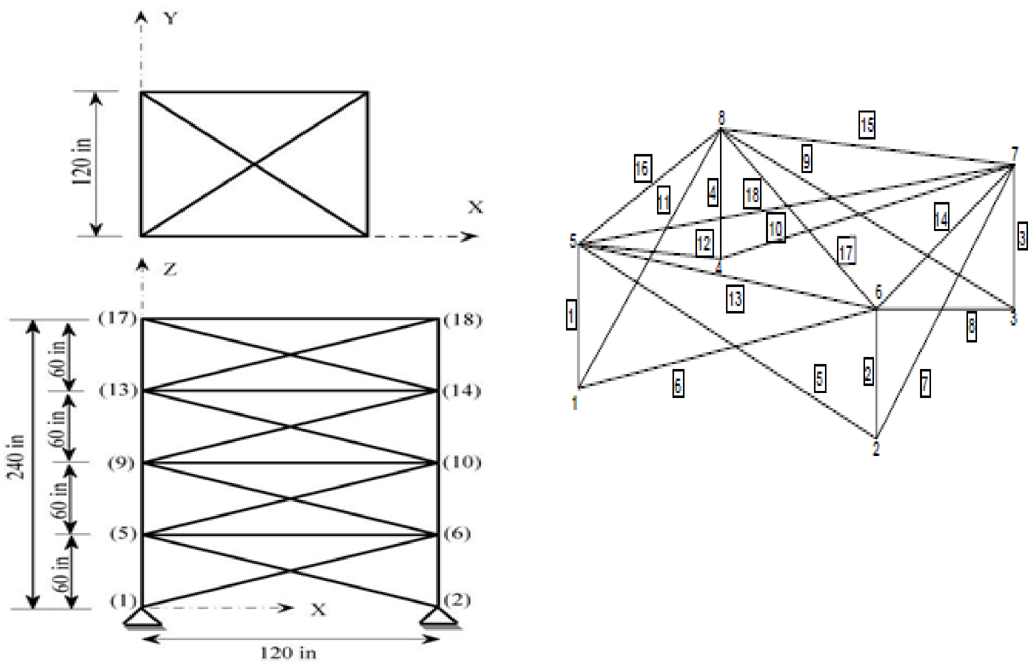
CHAPTER 4

ANALYSIS FOR STRESS AND DISPLACEMENT IN SPACE TRUSSES USING (ITERATIVE, OPTIMIZATION, HYBRID) METHODS

4.1. Iterative optimization and Hybrid methods for space trusses

4.1.1. (72) bar space truss (indeterminate system)

The sixth design is a 72-bar spatial truss as shown in Figure 4.1. For the truss members, the Young's modulus is 0.1 lb/in^3 and the material density is 10^4ksi. Using symmetry, the 72 bars are separated into 16 groups [10]. They are shown as:



(a) (b)

Figure 4.1. Scheme of the 72-bar spatial truss: (a) top and side view, (b) element and node numbering pattern for first story.

(1)A1 – A4, (2) A5 – A12, (3) A13 – A16, (4) A17 – A18, (5) A19 – A22, (6) A20 – A30, (7) A31 – A34, (8) A35 – A36, (9) A37 – A40, (10) A41 – A48, (11) A49 – A52, (12) A53 – A54, (13) A55 – A58, (14) A59 – A62, (15) A63 – A70, (16) A71 –A72.

The loading conditions that the truss structure is subjected to are shown below in Table 4.1. For all directions, the maximum nodal displacements are limited to ±0.25 for all free nodes. The minimum and maximum cross-sectional areas for each member are 0.1 in^2 and 4 in^2.

Table 4.1. Loading conditions for the 72-bar spatial truss.

Node	**Condition1 (kips)**			**Condition 2 (kips)**		
	PX	**PY**	**PZ**	**PX**	**PY**	**PZ**
17	5.0	5.0	-5.0	0.0	0.0	-5.0
18	0.0	0.0	0.0	0.0	0.0	-5.0
19	0.0	0.0	0.0	0.0	0.0	-5.0
20	0.0	0.0	0.0	0.0	0.0	-5.0

Table 4. 2. The Result for 72bar space truss

Elem No.	**Area for stress (in^2)**	**Area for displacement (in^2)**	**Area for optimization (in^2)**	**Area for hybrid (in^2)**
A1 – A4	0.1000	0.7762	2.0901	0.9558
A5-A12	0.1000	0.7762	0.5674	0.6288
A13-A16	0.1000	0.7762	0.4793	0.1676
A17-A18	0.1000	0.7762	0.3198	0.1382
A19-A22	0.1000	0.7762	0.7309	0.8727
A23-A30	0.1000	0.7762	0.5543	0.6315
A31-A34	0.1000	0.7762	0.2821	0.2174
A35-A36	0.1000	0.7762	0.4615	0.1817
A37-A40	0.1000	0.7762	0.5608	0.6406
A41-A48	0.1000	0.7762	0.4169	0.5662
A49-A52	0.1000	0.7762	0.4285	0.1673
A53-A54	0.1000	0.7762	0.3950	0.2410
A55-A58	0.1000	0.7762	0.5051	0.1639
A59-A62	0.1000	0.7762	0.8146	0.7988
A63-A70	0.1000	0.7762	0.8168	0.7657
A70-72	0.1000	0.7762	0.5784	0.7397

Table 4.3. The weight for 72 for iterative - optimization and hybrid method

Weight (Ib)	Condition1,2
Iterative stress	85.3090
Iterative displacement	662.1329
optimization	501.8493
Hybrid	450.5994

4.1.2. (25) bar space truss (indeterminate system)

The seventh design covers optimizing the size of a 25-bar spatial truss. This is shown in Figure 4.2. The Young's modulus was 10^4ksi and the material density was 0.1 lb/inch^3. Eight groups were formed from the 25 members. They are broken down as: (1) A_1, (2) $A_2 - A_5$, (3) $A_6 - A_9$, (4) $A_{10} - A_{11}$, (5) $A_{12} - A_{13}$, (6) $A_{14} - A_{17}$, (7) $A_{18} - A_{21}$, and (8) $A_{22} - A_{25}$.

The truss system faces the multiply loading conditions from Table 4.4. For every direction of all the free nodes, the maximum nodal displacement is limited to ±0.35. For every design, the allowable tension is the same. The allowable compressive stresses are dependent upon member length. This data is shown in Table 4.5. The cross-sectional areas of each is in the range between 0.01 in^2 and 3.4 in^2.

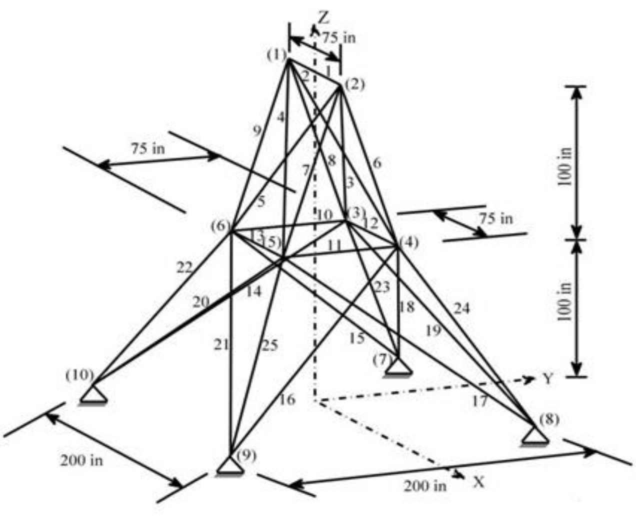


Figure 4.2. Scheme of the 25-bar spatial truss structure.

Table 4.4. Loading conditions for the 25-bar spatial truss.

Node	**Condition1(kips)**			**Condition 2 (kips)**		
	PX	**PY**	**PZ**	**PX**	**PY**	**PZ**
1	0.0	20.0	-5.0	1.0	10.0	-5.0
2	0.0	-20.0	-5.0	0.0	10.0	-5.0
3	0.0	0.0	0.0	0.5	0.0	0.0
6	0.0	0.0	0.0	0.5	0.0	0.0

Table 4.5. Allowable stress values for the 25-bar spatial truss.

Element group	**Allowable compressive stress(ksi)**	**Allowable tension stress(ksi)**
1	35.092	40.0
2	11.590	40.0
3	17.305	40.0
4	35.092	40.0
5	35.092	40.0
6	6.759	40.0
7	6.959	40.0
8	11.082	40.0

Table 4.6. The Result for 25 bar space truss

Elem No.	**Area for stress (in^2)**	**Area for displacement (in^2)**	**Area for optimization (in^2)**	**Area for hybrid (in^2)**
A1	0.0100	0.0189	0.2036	0.0178
A2-A5	1.2492	2.3555	2.1271	2.2160
A6-A9	1.1166	2.1055	2.9174	2.5778
A10-A11	0.0100	0.0189	0.2603	0.0130
A12-A13	0.0100	0.0189	0.1591	0.0186
A14-A17	0.5526	1.0419	0.7159	0.7175
A18-A21	1.6512	3.1137	1.6633	1.7170
A22-A25	1.3367	2.5205	2.6194	2.7287

Table 4.7. The weight for 25 for iterative - optimization and hybrid method

Weight (Ib)	**Condition1,2**
Iterative stress	344.3266
Iterative displacement	649.2791
optimization	555.7091
hybrid	548.4767

Conclusion

For the 25 and 72 bar space trusses, the best results are found using the hybrid method for load conditions 1 and 2 because it has the least weight.

CHAPTER 5

CONCLUSION

Optimization of truss structures is hefty because complexity that arises from various variables and constraints need special algorithms. This research was carried out to find the best value for minimum weight of the truss. This is because lower weight means less materials, which means less cost. Every method used in decreasing the structural weight aim for an optimal design with variables under specific constraints. The thesis first hypothesized that the suggested algorithm would return the best solutions for nearly any weight optimization situation for steel trusses. The research conclusions as are follows:

1- Iterative Method: Forty-three planar truss cases and two for space trusses were applied using the MAT-LAB software. This revealed a short computation period without optimal results.

2- Optimization Method: Forty-three planar truss cases and two space truss cases were established. There was no mathematical, or direct, solution found. The best solution can be estimated using this method but it is time-consuming and the length it takes depends on how many variables and variable limits exist.

3- Finite Search Method: This method was carried out for forty-three planar truss cases and two space truss cases. This method takes a longer time than both the iterative and optimization methods. However, this method provides the best solution.

4- Hybrid Method: The hybrid method was done for five planar truss and two space truss cases. Although there are many optimization algorithms, they are all very similar. It was shown that when combining two methods, a better solution is found than when using one alone. This method also provides a faster solution and improves time spent on calculations.

In the end, the hybrid method was discovered as the best method for finding the minimum truss structure weight without exceeding the allowable constraints of stress and displacement.

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