CROSS SECTIONS OPTIMIZATION OF PLANE TRUSSES FOR VARIOUS SPANS AND DEPTHS

SUMAYAH ABDULSALAM MUSTAFA

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Cross Sections Optimization of Plane Trusses for Various Spans and Depths

by

Sumayah Abdulsalam Mustafa

(1332011008)

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DECLARATION OF THE THESIS

Author's full name : SUMAYAH ABDULSALAM MUSTAFA

Date of birth : 02-11-1964

Title : CROSS SECTIONS OPTIMIZATION OF PLANE TRUSSES FOR VARIOUS SPANS AND DEPTHS

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MOHD ZULHAM AFFANDI MOHD ZAHID

NAME OF SUPERVISOR

Mohd Zulham Affandi Bin Mohd Zahid
Pengerusi Rancangan
Sarjana Muda Teknologi Kejuruteraan Awam (Pembinaan) RY
Fakulti Teknologi Kejuruteraan
Universiti Malaysia Perlis

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LIST OF ABBREVIATION

AGA	Augmented Genetic Algorithm
BS	British Standard
D.L	Dead Load
FEA	Finite Element Analysis
FEM	Finite Element Method
FSD	Fully Stressed Design
GA	Genetic Algorithm
GUI	Graphical User Interface
L.L	Live Load
Opt. W	Optimal Weight
Prac. W	Practical Weight
SA	Simulated Annealing
TS	Tabu Search

LIST OF SYMBOLS

B	Width of section (mm)
D	Depth of section (mm)
L	Length of the member (mm)
t	Thickness of the web (mm)
T	Thickness of the flange (mm)
I_x	Second moment of area about the major axis (mm^4)
I_y	Second moment of area about the minor axis (mm^4)
ε	Constant $(275/ \rho_c)^{0.5}$
f_c	Compressive stress due to axial force (N/m^2)
F_c	Compressive axial force (kN)
F_t	Tensile axial force (kN)
γ	Specific weight of steel (density), kN/m^3
ρ_y	Design strength of steel, MPa
X_i^s	Size section variable of i member of truss
E	Material young’s modulus, GPa
Ø	Shape factor
γ_f	Partial Load Factor
r_o	Outside Radius of the Cross Section
r_i	Inner Radius of the Cross Section
r	Inertia Radius
σ	Allowable Stress
σ_{cr}	Stress Corresponding Critical Loading
F_{cr}	Critical Load

ε	Strain
δ	Member Deformation
K	Constant Relate to the End Support Constraint
UA	Angle Section in Staad (BS)
TUB	Tube Section in Staad (BS)
PIP	Pipe Section in Staad (BS)
CH	Channel Section in Staad (BS)
λ	Slenderness Ratio
l_e	Effective Length of Member

Keratan Rentas Optimum Kekuda Satah dengan Rentang dan Kedalaman yang Pelbagai

ABSTRAK

Kekuda keluli digunakan secara meluas di dunia dan wujud motivasi berterusan untuk penyelidikan di dalam rekabentuk struktur optimum. Di dalam kejuruteraan awam, kekuda yang mempunyai berat optimum amat penting untuk pengangkutan dan pengurangan kos elemen dan juga kerja pembinaan sambungan yang dipermudahkan. Satu lagi kelebihan kekuda yang mempunyai berat optimum ialah perkongsian kapasiti beban yang minimum yang ditanggung oleh struktur itu sendiri. Pengoptimuman struktur juga amat penting dalam industri pesawat dan kereta yang mana struktur yang lebih ringan membawa maksud ekonomi tenaga yang lebih baik. Sewajarnya, banyak rujukan sejak dua dekad terakhir dalam analisis, rekabentuk dan pengotimuman kekuda. Tetapi, masih sedikit bilangan penyelidik terlibat dalam masalah parameter keratan rentas kekuda. Rekabentuk pengoptimuman kekuda perlu dilakukan mengikut dua keperluan penting. Pertama, susun atur geometri terbaik untuk anggota struktur dan nod perlu dikenalpasti, dan kedua adalah keratan rentas mencukupi perlu dikenalpasti. Kebiasaanya, wujud keperluan bentuk yang optimum dan agihan keratan rentas yang diadaptasi untuk beban luaran. Banyak kajian lepas menggunakan luas keratan rentas sebagai pemboleh ubah rekabentuk berterusan, walaupun, penggunaan prosedur pengoptimuman berterusan adalah lebih tepat, tetapi ia akan menjurus kepada saiz yang tidak wujud dan sebarang percubaan untuk mengantikan nilai tersebut kepada nilai terdekat boleh menjadikan kerja rekabentuk tersebut lebih berat. Kesannya, penyelesaian luas akan mencukupi jika prosedur rekabentuk memasukkan pengunaan luas keratan rentas sebagai pembolehubah rekabentuk diskrit daripada saiz yang ada, dan juga jika rekabentuk tersebut mengambil kira bentuk keratan rentas yang effektif pada permulaan proses. Ini adalah topik untuk penyelidikan ini iaitu untuk mengkaji kesan bentuk keratan rentas pada masalah kekuda satah optimum. Ini akan dilakukan menggunakan kaedah elemen tak terhingga dan elemen linear mudah dengan bantuan analisis struktur keluli dan perisian rekabentuk STAAD. Untuk tujuan itu, empat keratan keluli guling iaitu sesiku, tiub, saluran, dan paip yang digunakan dalam industri kekuda bumbung, dipertimbangkan dalam kajian ini. Tambahan lagi, dalam penghasilan komponen strucktur, faktor ciri-ciri bukanlah factor tunggal yang dipertimbangkan, tetapi, faktor geometri juga adalah penting yang diwakili oleh faktor bentuk komponen, iaitu satu pengukuran kecekapan dalam penggunaan bahan. Hasil kajian ini membuktikan bentuk keratan rentas yang dipilih mempunyai kesan penting pada berat optimum kekuda dengan geometri, beban dan penyokong yang sama. Keratan rentas paip dan tiub menawarkan berat kekuda yang paling kurang. Mansard dan Pratt adalah kekuda yang paling baik pada nisbah rentang kepada kedalaman bersamaan dengan enam.

Cross section optimization of Plane Trusses for Different Spans and Depths

ABSTRACT

Steel trusses are widely utilized in real-world applications and a continuing motivation for research in optimal structural design exists. In civil engineering, weight optimized trusses are convenient since the easier transportation and less costly structural parts as well as construction work in connection with the build-up is simplified. One more advantage of developing a weight optimized truss is the fact that the minimum share of the load capacity is enrolled by the structure itself. Structural optimization is also very important in the aircraft and car industry whereas a much lighter structure often means a much better energy economy. Accordingly, a rich literature has advanced within the last two decades in analysis and design as well as optimization of truss. Still, only a diminutive number of researchers dealt with the problem of parameterization of the truss cross section. The optimization design of trusses needs to be carried out in accordance to two essential requirements. First the best geometrical layout for members and nodes requires being determined, and second the best adequate cross-sections need to be determined. Generally there is need to exist an optimum shape and a cross-section distribution that is definitely adapted for external loads. Many previous studies, use the areas of cross sections as a continuous design variable, although, the use of a continuous optimization procedure usually more accurate, but it will lead to non-available sizes and any trail to replace those values by the nearest available sizes can make the design unnecessarily heavier. Consequently, solution of the area will be adequate if the design procedure includes the use of cross-sectional areas as discrete design variable from available sizes, as well as if the design takes into account the effective cross section shape at the start of process. This is the topic of this paper, to study the effect of the cross section shape on the optimization of plane trusses problem. This is going to be done by using finite element method and simple linear element with the aid of steel structural analysis and design STAAD software. Four rolled steel sections (angle, tube, channel, and pipe) which are used in industrial roof trusses are applied for this purpose. Furthermore, in producing a structure element, the material properties is not the only factor considered, however, the geometry properties also is vital factor to be considered which is represented by component's shape factor, that measures the efficiency of the material usage. Outcome results of this research prove that the chosen cross section shape has a significant effect on the optimum truss weight for exact same geometry of the truss type under the similar circumstances of loading and support. Pipe and tube section shapes offer least truss weight. The best truss shape and topology concerns with Mansard and Pratt truss topology at span over depth ratio of six.

CHAPTER 1

INTRODUCTION

1.1 Overview

The expression optimal structure is extremely vague. The reason is a structure may be optimal in different aspects. These different aspects are known as objectives, and can for instance be the weight, cost or stiffness of the structure. Consequently, structural optimization is the subject of making an assemblage of materials to sustain loads in the best way. The first such specification that comes to mind may be to make the structure as light as possible to minimize weight. Another idea of “best” could be to make the structure as stiff as possible, and yet another one could be to make it as insensitive to buckling instability as possible. Clearly, such maximizations or minimizations cannot be performed without any constraints. For instance, if there is no limitation on the amount of material that can be used, the structure can be made stiff without limit, and we have an optimization problem without a well-defined solution (Klarbring, 2008).

Structural optimization offers an organized strategy to use further than the standard analysis of a few candidate structures that have been selected depending on designer’s experience and intuition. According to Coello, Rudnick, & Christiansen (1994), Galileo Galilei definitely seems to be the first scientist to research structural optimization in his work on the bending of beams. Advanced optimization strategies with developed computer facility assist to obtain new better designs which would likely be otherwise remained undiscovered. The optimum design of a truss should satisfy the minimization of the truss cost within the role of various constraints such as proper stress levels, displacement limits and element stability conditions. However, weight optimization plays a major role in engineering fields due to its significant effect to overall costs. So, the optimization should be carried out with as little material as possible. The fundamental concepts of structural optimization have been presented in the text books of Vanderplaats (1984), Arora (1989), Haftka & Gürdal (1992), and Farkas & Jármai (1997).

Generally, the basic approaches of structural optimization for trusses could be divided into three sub problems: sizing, shaping, and topology optimization.

In sizing optimization, the idea is to change the cross-section dimensions or properties until finding the most adequate cross-sections that gives a suitable profile for each truss member for external loads (Gil & Andreu, 2001). Cross-sectional optimization, the most heavily researched of these three techniques. Considers a fixed topology and geometry (the number of beams and joints, their connection, and locations) and gets the shape of the beams that will be the best. Either in terms of mass or stiffness, support a certain set of loads. The parameters of the structure that are changed during optimization, called the design variables Such as, the radius and thickness of each tube element. An example of this technique in practice is the design of the beams that are used to build utility transmission towers whereas savings of only some hundred dollars in material costs, while multiplied by the thousands of towers required for a new transmission way, will be a considerable gain (Hansen & Vanderplaats, 1990; Smith, Hodgins, Oppenheim, & Witkin, 2002). In this sizing optimization, the requirements of appropriate steel design code such as British standard 5950-1:2000 and other relevant recommendations BS 6399-1, BS 6399-3 have to be taken into consideration to ensure the optimized structure will be usable. The use of design code and considerations provides on several constraints which are easily executed in this method with desecrate design variables and by aid of STAAD program.

The design of the structural shape based on engineer's criteria partly depends on aesthetical, economical, construction techniques and environmental aspects. Furthermore, in the shape optimization, the target is to find the best geometrical layout of the members and nodes, and the nodal coordinates of the truss with fixed topology are chosen as design variables (Ohsaki, 1998).

Topology optimization is to seek the best loading path in the unlimited topology combinations by changing the amount and location of materials to save the most materials (Ruiyi, Gui, & Zijie, 2009).

This study is going to use Finite element method by the aid of STAAD Pro software for analysis and sizing optimization design for six trusses types which are common used for spans from 12m to 30ms. These trusses will be considered as models to analyse the impact of sections shape on the optimal truss weight. Hence, four light weight commonly used sections are applied for this purpose (see Fig. 1.1).

Figure 1.1: Common light weight sections of roof trusses (Davison & Owens, 2012)

Besides, many of previous existing researches employ the areas of cross sections as design variables without heightening to the shape of cross section at the beginning of the process: accordingly the result area may be not sufficient in case that the designer do not select the effective shape than others. This is true if the shape of the sections has an impact on the needed to be designed section area of the truss members. Ashby (2002) showed that how the shape modified the behaviour of material and the shaped sections increase the efficiency of the material. That is, according to the researcher knowledge, there is no similar practical study has been carried out to compare the effect of the changed section shape of the designed area of the truss members under same external loads and constraints.

When the designer use area or range of areas as discrete variables, the optimum cross sectional areas of the truss bars will lead to non-available sizes and probably not be found on the market. The trail to substitute those values by the nearest available commercial sizes make the design infeasible or uneconomical owing to the use of unnecessary weight, which is not practically recommended (Croce & Ferreira, 2004; Dominguez, Stiharu, & Sedaghati, 2006). This research is going to address this issue by utilizing the effective cross section from practical library commercially available sizes for a fixed configuration and topology of the roof truss.

1.2 Problem Statements

A common structural design problem is the weight minimization of the trusses which is formulated by choosing a set of design variables that identify the structural and architectural configuration of the system. The structures are often governed by stress and displacement limitations, and the design variables may be continuous or discrete. In practice, it is often suitable to select design variables (just like cross-sectional area) from commercially offered sizes. Despite of the fact that the application of a continuous optimization process is often more straightforward, but definitely will lead to non-available sizes and then every attempt to alternate those values by the nearest offered