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A Review on Optimization of Industrial Trusses

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Abstract*: We know that Asian country is that the quickest growing country within the world. Industries square measure increasing day by day. These industries square measure engineered victimization steel truss. If correct style and analyses aren't done there's an opportunity of increase in weight of truss that successively will increase the price of construction. Therefore, to cut back and optimize the truss correct style and analyses is needed. The study aims to optimize and analyze a Warren, Pratt and Howe steel trusses and scrutiny Warren truss with different Pratt and Howe trusses. Existing structure steel trusses was optimized for minimum weight, in unnatural with allowable stresses and deflections. The cross-sectional space of the truss members is taken as a style variable. Existing pure mathematics and loading conditions of the truss square measure sized to mimic true world surroundings. The steel trusses were optimized victimization the planning optimization tool as 1st order optimization methodology in ANSYS and it's extended to match for best appropriate truss pure mathematics for minimum weight. Mesh studies were performed on all ANSYS finite component models to make sure answer convergence. A comparison of the trusses was created by evaluating the minimum margin of safety altogether truss members. To create a good analysis all trusses, have identical geometries and loading conditions. The intent is to match that truss is additional economical once constructing a truss. Finally, it's complete that Warren truss is showing high stiffness to weight magnitude relation over different trusses when optimization.

***Keywords*: Warren truss, Pratt truss, Howe truss, Steel, Optimization, Finite Element Method.**

1. Introduction

The members that are joined at the joints are termed as truss. The truss members are unremarkably straight. It is formed by change of integrity completely different members relying upon different span, slopes, kind and sections. Steel trusses are increasing in construction of business buildings. Because of increase in construction of steel buildings everywhere there is a necessity of lowering the weight of truss. Structural improvement has become a valuable tool for engineers and designers in recent years. Although it has been applied for over forty years, improvement in engineering has not been a normally used style tool until high performance computing systems were created wide out there. Structures have become lighter, stronger, and cheaper as business adopts higher styles of improvement. This kind of downside determination and merchandise improvement is currently a vital a part of the planning method in today's engineering business. To better perceive improvement of structures and therefore the focus of this paper, two definitions should be expressed. The first definition is that of the structure, together with all implications and capabilities within the static analysis of such systems. The second definition applies thereto of structural improvement, a lot of specifically the improvement of size and form. A structure could be a set of nodes (vertices) that area unit connected by a collection of components (edges). This includes all plane (2D) and house (3D) truss and frame structures. Masses are also placed at nodes to exert a force or moment on the structure. Constraints are also placed at nodes to restrain the structure from translation or rotation caused by nodal masses. A valid structure should constrain a minimum of all six degrees of freedom as a system, and over constraint can usually turn out stiffer structures. All components area unit related to a fabric outlined by a minimum of 2 values: modulus of physical property (E) and Poisson's quantitative relation(μ). These values outline the element's behavior below static linear elastic loading conditions. Values used just for the improvement method embody the element's yield strength (σ) and unit weight (Kg) or mass density (ρ). These values area unit used for stress limit comparison and structural mass.

A. Standard Form of the Optimal Design Problem

Design optimisation seeks the simplest values of style variables, to achieve, among sure constraints, placed on the system behaviour, allowable stresses, geometry, or alternative factors, its goal of optimality outlined by a vector of objective functions, for mere environmental conditions. Mathematically, style optimisation could also be solid within the following normal form.

B. Statement of the Optimization Problem

An optimization or a mathematical programming problem can be stated as follows.

Find $X = \{ x_1, x_2, x_3, \ldots\ldots\ldots x_n \}$ which minimizes f (X)

Subject to the constraints

$gj(X) \le 0, j = 1, 2, \ldots, m$
$lj(X) = 0, j = 1, 2, \ldots, p$

Where X is an n-dimensional vector called the design vector, f (X) is termed the objective function, and gj (X) and lj (X) are

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known as inequality and equality constraints, respectively. The number of variables n and the number of constraints m and or p need not be related in any way. The problem stated in Equation is called a constrained optimization problem. Some optimization problems do not involve any constraints and can be stated as,

Find X = { x_1 , x_2 , x_3,.......... x_n } which minimizes f (X)

Such problems are called unconstrained optimization problems.

C. Formulation of Optimization Problem

- *Objective Function:* Minimize Weight

Member weight = Length x Member cross-sectional area x density

Truss weight = $\sum_{i=1}^{i=n} LixAixp$

Design Constraints: Stress & Nodal

Direct stress < 125 MPa

Nodal displacement < 25 mm

- *Design Variables:* Members cross-sectional Area
- *Starting Point:* 50000 sq.mm

D. Load Consideration

Dead Load: Dead load on the roof trusses in single structure industrial buildings consists of loading of claddings and loading of purlins, self-weight of the trusses additionally to the weight of bracings etc.

Live Load: The load on roof trusses incorporates the attractive force load because of erection and mating furthermore as dirt load etc. and the intensity is taken as per IS:875-1987.

Wind Load: Wind load on the roof trusses, unless the roof slope is just too high, would be sometimes uplift force perpendicular to the roof, because of suction impact of the wind processing over the roof. Wind load is taken into account as per IS 875- part III.

E. Load Combination

1) DL+ LL
2) 1.5DL+1.5LL
3) 1.5DL+1.5WL0
4) 1.5DL+1.5WL90
5) 0.9DL+1.5WL0
6) 0.9DL+1.5WL90
7) 1.2DL+1.2LL+1.2WL90
8) 1.2DL+1.2LL+1.2WL90

F. Objectives

The main objective our studies are as follows;

- Giving the most economical design.
- Reducing the quantity of steel required.
- Reducing the overall weight of the structure there by reducing the cost of columns.

2. Literature Review

1) Rohan S. Mutnal - Analysis and Design of Structural Components for Industrial Steel Structure by using Software Package STAAD PRO.V8i

In their project work, general building information was adopted for the study and is well analyzed and designed. The project was undertaken at Belagavi location. The analysis and arising with was done in keeping with the standard specification to the potential extend. The analysis of structure was done exploitation the code package STAAD skilled.V8i. All the structural parts were designed manually. The foremost objective of this study was to line up, analyze and design associate industrial steel structure. The analysis and elegance were done according to customary specifications to the potential extend which proven to be premium code of nice potential in analysis and elegance sections of construction business.

Use of MS-EXCEL for vogue is understood. Use of AutoCAD for drawings is understood.

2) Handbook of typified designs for strutures with steel roof trusses (with and without cranes) (based on IS codes) SP: 38(S&T)-1987

Handbook of typified styles for strutures with steel roof trusses (with and while not cranes) (based on IS codes) SP: 38(S&T)-1987 Project B-8 -Typification of commercial Structures. the thing of the project B8 was to typify at national level the common sorts of industrial structures used in lightweight engineering industries, warehouses, workshops and storage sheds, and to get economical styles beneath these conditions. The main objective of typification of commercial structures is to scale back the variety to the minimum and supply normal ready-made styles in order that the structures might be simply mass created and created out there to the user almost off the shelf.

The project on typification of commercial structures concerned the subsequent three main tasks before preparation of typified designs:

a) Task one - Survey and classification of commercial structures into completely different types;

b) Task II - Identification of commercial structures recurrent an outsized range of times within the country, that area unit amenable to typification from the classified list ready throughout Task 1.

c) Task III -- Specifying the weather of the commercial structures to be typified taking into thought variety of parameters, like structures with cranes and while not cranes, span, length, height, support conditions, slope of roof, wind and earthquake forces, spacing, field and look connections, material (steel, strengthened concrete). etc. The tvpification of structures with steel roof trusses (with and while not cranes)

having A-type additionally as shelter roof kind trusses supported on columns.

3) Vivek Garg, (2015) - Optimization of industrial truss

They have thought of a truss of span 16m with whole completely different geometries and sections to induce the optimum weight. He has performed the analyses exploitation Staad skilled package. The analysis results are compared to induce optimum truss design. The results indicate that A-type truss has lesser weight compared to other truss geometries. The truss consists of tube or sq. hollow section is having galore lesser weight compared to angle section. The optimum truss slope is found nearly 24º. The truss with rigid affiliation between members is found heavier than the truss with pin affiliation.

4) Siti Halipah Ibrahim, Qairuniza Roslan, Rohaida Affandi, Abdul Wafi Razali - Study on the optimum roof type with 30° roof angle to enhance natural ventilation and air circulation of a passive design.

The planned optimum roof was styled to boost the passive design. The roof was designed with a 30° pitch and five hundredth gap. The 30° roof pitch was chosen as a result of this pitch is suggested for straight forward maintenance functions and quicker air movement compared to different pitches. The openings additionally enhance natural ventilation and permit for effective air circulation within the house. The optimum roof is intended to tackle this matter by reducing the warming within the house, particularly throughout the hottest hours of the day. The recent air exits supported the variations in air density and thanks to wind. During this study, the optimum roof was tested on a small-scale model and verified by simulation victimization process fluid dynamic (CFD) code, specifically ANSYS eighteen.0. From the information obtained, it was tested that the gap within the roof reduced the indoor temperature. In conclusion, the optimum roof might improve the passive style and facilitate to reduce warming within a building.

5) Muhammad Umair Saleem - Design optimization of pre-engineered steel truss buildings

The construction style based mostly optimization of pre-engineered industrial steel truss buildings. So as to realize it, a good vary of commercial steel buildings is chosen for analysis and style of integrated standard industrial buildings with truss roofing systems.

The study comprised of 3 main components. Within the initial half, eave height of the truss was style variable whereas the opposite geometrical and loading parameters were unbroken constant. By varied the peak of truss, its impact on the truss structural response and on its weight is decided. By doing therefore, the most optimum height of the truss assembly is decided. Within the second half, different types of sections like hot rolled hollow tubes shapes and hollow sections were taken as style variables and also the truss weight and potency is further optimized. within the third half, an entire industrial frame is modeled with 2 totally different configurations of supporting columns like truss columns and hot rolled I form columns. The better of the 2 designed frames was thought-about for the more study and a pc model of a full scale pre-engineered steel truss building was prepared to judge the important time weight of pre-engineered steel truss building.

6) P. Satheesh Kumar Reddy & CH. Nagaraju - Structural optimization of different truss members using finite element analysis for minimum weight

This paper aims to optimize and analyze a Warren, Pratt and Howe steel trusses and comparison Warren truss with different Pratt and Howe trusses. Existing structure steel trusses was optimized for minimum weight, in constrained with allowable stresses and deflections. The cross-sectional space of the truss members is taken as a style variable. Existing pure mathematics and loading conditions of the truss square measure sized to mimic true world surroundings.

Every try was created to stick to each state and federal laws.

The steel trusses were optimized exploitation the planning optimisation tool as 1st order optimisation methodology in ANSYS and it's extended to check for best appropriate truss pure mathematics for minimum weight. Mesh studies were performed on all ANSYS finite part models to confirm resolution convergence. A comparison of the trusses was created by evaluating the minimum margin of safety altogether truss members. To form a good analysis all trusses have identical geometries and loading conditions. The intent is to check that truss is a lot of economical once constructing a truss.

7) A. Jayaraman, (Vol. 3, Oct. 2014)

Their paper presents a study on behaviour and economical of roof trusses and purlins by comparison of limit state and dealing stress methodology. The studies reveal that the theoretical investigations limit state methodology style has high bending strength, high load caring capability, minimum deflection and minimum native buckling & distortional buckling compare to the operating stress methodology. However, operating stress methodology is most economical compare to the limit state methodology style. In operating stress methodology, the entire weight of steel is needed 1502 metric weight unit and total rate of value is RS eighty-two, 610. The limit state methodology the total weight of steel is needed 2308 metric weight unit and total rate of value is RS 126,940. during this paper it's found that for limit state methodology the entire amount of weight of steel and rate of value is thirty-four.78% on top of the operating stress method.

3. Methodology

A. Trusses and their Geometries

Truss **-** These square measure framed assemblies typically carrying hundreds within the plane of the frame. The individual members square measure primarily in tension or compression which can be attended with some bending moment. A truss may be an easy structure whose member’s square measure subject to axial compression and tension solely and however not bending moment. The most common truss sort’s square measure Warren truss, Pratt truss and Howe truss. Warren truss contains a series of symmetrical triangles or equilateral triangles. to extend the span length of the span, verticals square measure value-added for Warren Truss. Pratt truss is characterized by having its diagonal members (except the tip diagonals) slanted down towards the center of the bridge span. Underneath such structural arrangement, once subject to external hundreds tension is evoked in diagonal members whereas the vertical members tackle compressive forces. Hence, dilatant and lighter steel or iron is often used as materials for diagonal members so a lot of economic structure is often increased. the look of Howe truss is that the opposite to it of Pratt truss in which the diagonal members square measure slanted within the direction opposite to it of Pratt truss (i.e. aslant aloof from the center of bridge span) and in and of itself compressive forces square measure generated in diagonal members. Hence, it's not economical to use steel members to handle compressive force.

Table 1: Existing and Allowable Data for Different Trusses

Design Parameters	Warren Truss	Howe Truss	Pratt Truss
Number of truss members	19	21	21
Max. Allowable Stress (MPa)	125	125	125
Max. Deflection (mm)	25	25	25
Total Weight of Truss members (kN)	14.45	16.71	16.75
No. of Joints	11	12	12
Cross sectional Area (Sq.mm)	50000	50000	50000

B. Material Properties

If the strain is just too high a designer has solely 2 selections. One is to extend cross sectional space and therefore the other is to revamp the pure mathematics of the truss to a lot of equally distribute load. Every of those selections have unfortunate tradeoffs. Increasing cross sectional space will increase weight that adds extra loading the truss has got to carry. It may also cause different geometric issues which can violate the look parameters of the bridge. Redesigning the truss pure mathematics adds to the amount of connections required within the truss and potential points of failure. Once these 2 choices aren't available the designer has no alternative however to travel for improvement which may cause the requirement for larger or smaller cross sectional space. The truss part is freelance of the moment of space so solely the conventional stresses square measure of main concern. Circular cross sections square measure best for bearing traditional stress but L-shape rolled sections square measure employed in this study due to their wide use and simple connation and square measure taken as per AISC manual with material as per ASTM-A36; Modulus of elasticity = 200 GPA, Poisson magnitude relation = zero.29, Yield strength = 250MPa, final strength = 1930MPa and density = 7860 kg/m^3. As issue of safety taken for the look is a pair of, therefore allowable stress is 125MPa. Analysis and improvement is performed victimization ANSYS software system.

C. Model Geometry, Element Type and Mesh

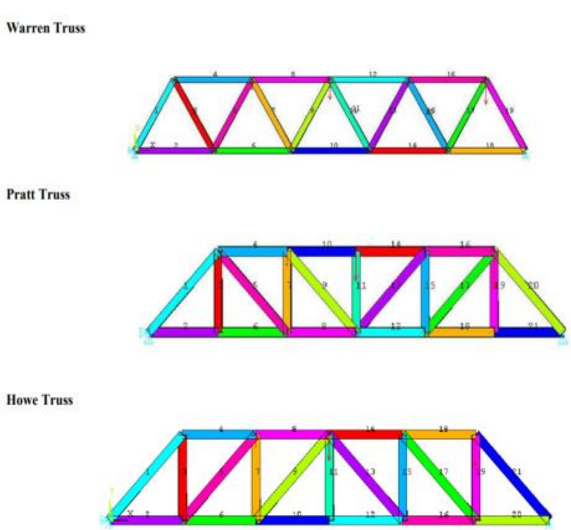

Fig. 1. 2D ANSYS FEM geometry

The CAD model of the truss was generated victimization nodes and parts in ANSYS. The members were modeled with nodes connections. Figure one shows this CAD model however they're connected to urge a nineteen bar Warren truss, twenty-one bar Pratt truss and twenty-one bars Howe truss. The left finish joints are pivoted and right finish joints restrained in vertical direction. The vertical hundreds acting downward are with magnitudes 200kN, 400kN and 500kN at the similar joints for all trusses.

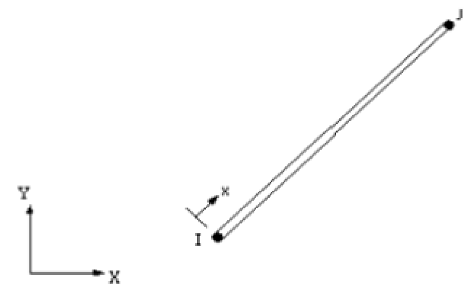

Fig. 2. Link-1 2D Spar

D. Loads and Boundary Conditions

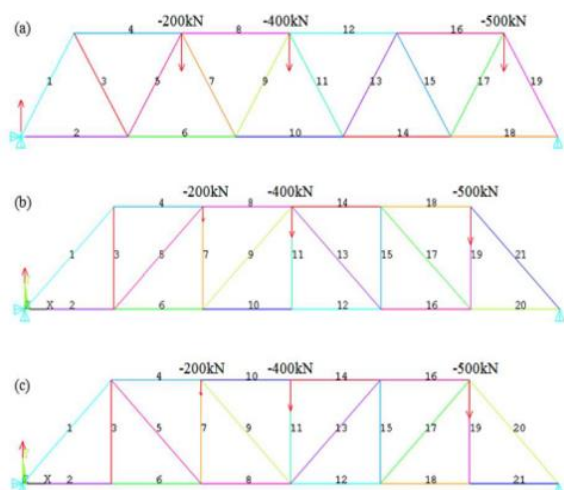

Fig. 3. (a) Warren truss, (b) Howe truss, (c) Pratt truss

The steel truss material was outlined as linear identical truss material. The inputs for the identical material area unit elastic modulus and Poisson magnitude relation. Hundreds were applied to the truss as per the free body diagram. The appliance purpose of these hundreds was at the nodes connecting the beams of the truss. The boundary conditions were set specified the truss is simply supported. this implies that left node is mounted in area and right node is ready as a stapled support. This interprets to restraining left node from movement within the x, y, and z direction likewise as a rotationally restricting it round the x and y axis. It additionally sets right node as restrained from movement within the y and z directions and also the rotationally restrained area unit around the x and y axis.

4. Results

The results of applying the analysis methodologies careful within the previous sections are bestowed within the following section. Results of the various trusses are bestowed alongside optimization of every candidate member. The results of this study can facilitate opt for the most effective truss for the important time loadings. The results of the second FEM are nodal displacements and stresses in every member within the axial direction.

The distribution of stresses throughout this model didn't vary considerably. a number of the members in compression and some of the members in tension. the sole distinction was the magnitude of the stresses in every truss.

A. Structural Analysis of Pre and Post Optimization of Truss Members

It is known before improvement warren truss is with most nodal displacement one.7855 metric linear unit wherever as in

Pratt and Howe trusses square measure a pair of.264 and 2.224 metric linear units severally.

When improvement most nodal displacement eighteen.99 mm where as in Pratt and Howe trusses square measure twenty.39 and 20.31 metric linear units severally. These values aren't profaned the look constraint. This shows Warren truss has high stiffness before improvement and when improvement. The distinction in nodal displacement magnitude between the models is often seen within the outline of ends up in Table a pair of. It's known that their square measure 2 zero force members just in case of Pratt and one zero force member in case of Howe trusses that isn't true in case of Warren truss as before and when improvement. When improvement stress constraint isn't any were exceeded with issue of safety a pair of as shown in Table three. It shows the important resistance of hundreds for Warren truss because of its geometrical structure is much better than Pratt and Howe trusses.

Table 2: Nodal Displacements among Different Trusses in mm

Node Joint	Pre – Optimization						Post - Optimization					
	Warren Truss		Pratt Truss		Howe Truss		Warren Truss		Pratt Truss		Howe Truss	
	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0.056	-0.993	0.083	-0.960	0.083	-1.042	1.420	-10.21	1.185	-8.403	1.206	-9.615
3	0.224	-1.653	0.166	-1.753	0.250	-1.878	2.876	-16.95	2.370	-14.43	2.406	-16.73
4	0.447	-1.655	0.333	-2.184	0.460	-2.224	4.339	-16.94	3.574	-19.20	3.616	-20.31
5	0.610	-1.066	0.506	-1.848	0.670	-1.923	5.793	-10.23	4.779	-14.46	4.827	-16.74
6	0.712	0	0.643	-1.202	0.843	-1.239	7.229	0	5.978	-8.450	6.028	-9.608
7	0.650	-0.513	0.780	0	0.980	0	6.508	-5.53	7.176	0	7.226	0
8	0.537	-1.406	0.724	-0.960	0.723	-0.959	5.067	-14.03	5.994	-8.403	5.999	-8.408
9	0.342	**-1.785**	0.557	-1.837	0.640	-1.834	3.607	**-18.99**	4.790	-15.62	4.792	-15.61
10	0.149	-1.409	0.347	**-2.264**	0.473	**-2.224**	2.148	-14.02	3.579	**-20.39**	3.592	**-20.31**
11	0.016	-0.642	0.137	-1.884	0.300	-1.886	0.701	-5.570	2.368	-15.60	2.391	-15.59
12			-0.035	-1.202	0.163	-1.203			1.162	-8.450	1.193	-8.460

Table 3: Axial Stresses among Different Truss Members

Element Number	Pre – Optimization			Post - Optimization		
	Warren Truss	Pratt Truss	Howe Truss	Warren Truss	Pratt Truss	Howe Truss
	Axial stress (MPa)	Axial stress (MPa)	Axial stress (MPa)	Axial stress (MPa)	Axial stress (MPa)	Axial stress (MPa)
1	-9.0963	-11.785	-11.785	-119.84	-120.48	-120.47
2	4.68	8.3333	8.3333	118.36	118.51	120.65
3	9.0963	**0**	8.3333	119.84	**0**	120.65
4	-9.36	-16.667	-8.3333	-120.05	-120.42	-120.65
5	-9.0963	11.785	-11.785	-119.84	120.48	-120.47
6	14.04	8.3333	16.667	121.33	118.51	120
7	4.4315	-8.3333	4.3333	117.73	-118.51	112.5
8	-16.32	16.667	-16.667	-121.66	120.42	-120
9	-4.4315	6.1283	-6.1283	-117.73	118.55	-119.8
10	**18.6**	**-21**	**21**	**121.9**	**-121.1**	**121.03**
Table 3 Contd.,						
11	-4.898	-8	**0**	-118.12	-118.45	**0**
12	-16.08	17.333	21	-121.63	120.54	121.03
13	4.898	5.1854	-5.1854	118.12	120.15	-117.21
14	13.56	-21	-17.333	121.22	-121.1	-120.19
15	-4.898	-3.6667	3.6667	-118.12	-113.32	114.87
16	-11.04	-17.333	17.333	-120.61	-120.54	120.19
17	4.898	5.1854	-5.1854	118.12	119.97	-117.22
18	8.52	13.667	-13.667	119.67	119.83	-119.8
19	-16.56	**0**	3.6667	-121.54	**0**	114.87
20	-	-19.328	13.667	-121.84	119.8	-121.84
21	-	13.667	-19.328	119.83	-121.31	119.83

B. Discussion on Optimized Results of Trusses

It is confirmed that optimized trusses are inside the boundaries of style constraints, currently it's need to research cross-sections of all the members might not be same, that isn't necessary since all the members aren't in an exceedingly position to take significant hundreds. Therefore, improvement tool in 2nd ANSYS FEM was wont to calculate optimum cross-sectional areas for each and {each} truss member in reducing weight of truss and their by reducing hundreds at joints inflicting reduction in stress levels. space of cross-sections of all the members are taken as a style variable, allowable stress within the members are taken as a state variable beside weight of every member as objective perform. it's known that there's a giant visit weight of the truss and space of cross-sections creating the truss optimized. the subsequent graphs and figures show reduction in structural weight in proportion with cross-sectional areas of individual members.

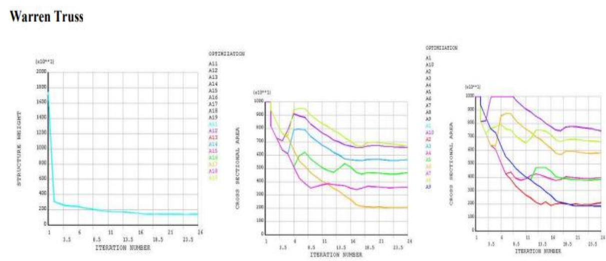

Fig. 4. Iteration wise reduction in structural weight and area of cross-sections for Warren truss members

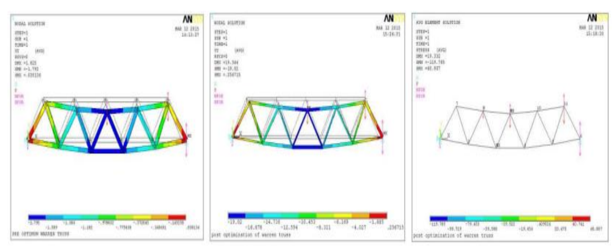

Fig. 5. Pre & post optimum finite element model and results obtained for warren truss

C. Margin of Safety

The ultimate goal of optimization for the development of a bridge is achieving a lower weight structure that has higher strength. Strength will be quantified by shrewd a margin of safety in every member. Margin of safety is outlined as in equation.

$$M.S. = \frac{Allowable\ Strength}{Actual\ Strength}$$

D. Steel Truss Margin of Safety

The intermediate alloy ASTM-A36 steel is associate degree isotropic material. This implies it's a similar strength in each direction. The fabric allowable for this strength solely varies with the sort of stress applied. Table four details the fabric allowable for steel material in compression and tension. The maximum axial stress in every member as computed was compared to the acceptable tension or compression material allowable.

Table 4: Allowable Stresses in Steel Material

ASTM-A36	Allowable (MPa)
$\sigma_{ty\ (Tensile)}$	250
$\sigma_{cy\ (Compressive)}$	250

The member stresses utilized in this calculation will found within the previous section. The ensuing axial M.S. is shown in Table five. It's known that margin of safety is bigger than one for all the members when improvement, and is additionally bigger than 2 for all the members with high issue of safety.

Table 5: Margin of Safety Calculations

Element Member	Warren truss		Pratt Truss		Howe Truss	
	Stress	M.S	Stress	M.S	Stress	M.S
1	-119.84	2.09	-120.48	2.08	-120.47	2.08
2	118.36	2.11	118.51	2.11	120.65	2.07
3	119.84	2.09	0	---	120.65	2.07
4	-120.05	2.08	-120.42	2.08	-120.65	2.07
5	-119.84	2.09	120.48	2.08	-120.47	2.08
6	121.33	2.06	118.51	2.11	120	2.08
7	117.73	2.12	-118.51	2.11	112.5	2.22
8	-121.66	2.05	120.42	2.08	-120	2.08
9	-117.73	2.12	118.55	2.11	-119.8	2.09
10	121.9	**2.05**	-121.1	2.06	121.03	2.07
11	-118.12	2.12	-118.45	2.11	0	---
12	-121.63	2.06	120.54	2.07	121.03	2.07
13	118.12	2.12	120.15	2.08	-117.21	2.13
14	121.22	2.06	-121.1	2.06	-120.19	2.08
15	-118.12	2.12	-113.32	2.21	114.87	2.18
16	-120.61	2.07	-120.54	2.07	120.19	2.08

Table 5 Contd.,

17	118.12	2.12	119.97	2.08	-117.22	2.13
18	119.67	2.09	119.83	2.09	-119.8	2.09
19	-121.54	2.06	0	---	114.87	2.18
20			-121.84	**2.05**	119.8	2.09
21			119.83	2.09	-121.31	**2.06**

1) Weight reduction in trusses

It is confirmed that optimized trusses area unit at intervals high margin of safety or issue of safety, currently it's need to guage the burden of the structural members in addition as trusses. it's confirmed that optimized trusses area unit at intervals high margin of safety or issue of safety, currently it's need to guage the burden of the structural members in addition as trusses.

Table 6: Weight Reduction and Convergence During Iterations

Iteration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Warren	17471	3068	2776	2557	2501	2426	2242	2163	1996	1894	1801	1751	1737	1697	1636	1552	1455
Pratt	18267	5948	5078	4667	4605	4283	3217	2905	2587	2521	2255	2209	2207	2149	2045	1974	1925
Howe	18267	5948	5078	4667	4605	4283	3217	2905	2587	2521	2255	2209	2207	2149	2045	1974	1925

Iteration	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Warren	1427	1450	1439	1437	1421	1416	**1414**	1416	1418	Converged...							
Pratt	1867	1842	1823	1814	1803	1772	1751	1736	1719	1713	1712	1716	1712	1697	1685	1673	**1670**
Howe	1867	1839	1806	1801	1776	1759	1714	1694	1701	1705	1703	1692	1695	1687	1677	**1676**	1677

Iteration	35	36	37	38	39	40	41
Warren	Converged...						
Pratt	1670.4	1673.1	1675.5	1670.5	1669.6	Converged...	
Howe	Converged...						

5. Conclusions

1) After the improvement Warren truss is with less weight compared to Pratt & Howe trusses for similar loading.
2) It is known that margin of safety is a lot of or less equal altogether trusses and additionally happy the look constraint.
3) It is known that nodal displacements at essential nodes also are a lot of area less equal and in limits.
4) It is known that their square measure two zero force members just {in case} of Pratt and one zero force member in case of Howe trusses that isn't true in case of Warren truss.
5) It shows the important resistance of masses for Warren truss because of its geometrical structure is much higher than Pratt and Howe trusses.
6) Construction of optimized 19-bar Warren truss is usually recommended compared to Pratt & Howe trusses.

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