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Topology Optimisation of Warren Trusses

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Abstract : In this study we have considered 9 Warren truss each with a distinct span and height and each truss was subjected to 9 loading conditions and 81 cases were formulated. Each case was optimized to get a target stress of 100 MPa in each member and the steel Take Off was calculated. This steel take off was compared with other span and height combinations of the Warren truss for the same loading condition and the mass used of the steel was compared. In this way optimisation results in the efficient utilization of material and hence reducing the cost of the structure.
Keywords: Fully Stressed Design, Optimisation, Warren truss

I. Introduction

The world limited in resources by all means, so it becomes necessary that the materials are put to its utmost service. This can be achieved by applying the concept of mathematical optimization to any relevant field. The main objective is to minimize cost of structure by maintaining its structural integrity and safety and to find the optimum parameters for construction. The parameters involved in the process of optimization are mostly contradictory in nature for instance, if one want to make structure to make the structure as light as possible i.e., to minimize weight or as stiff as possible one could make it more vulnerable to buckling or instability. Such maximizations or minimizations cannot be performed without putting 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. Quantities that are usually constrained in structural optimization problems are stresses, displacements and/or the geometry.

Andrew B. Templeman (1983) presented a paper stating major reason why only some research output in structural optimization has been applied to design practice is that very little of it satisfies the specific needs of its potential users. Randolph Thomas and Daniel Brown (1977) presented a paper for design of roof truss system using optimization, with mentioning cost function as a parameter and mentioned an algorithm encompassing the application of 8 optimization methods M. P. Saka (1991) presented a paper on optimization of structures and has carried out a lot of studies on structures where optimality criteria method has been employed. S. Rajasekaran (1983) presented a paper on Computer Aided Optimal Design of industrial roof, and the design procedure on the optimal design of industrial roof was carried out. M.Ohsaki (1995) presented a paper on optimal topologies and carried out a study keeping stress and displacement constraints under multiple static using genetic algorithms. Lluis Gil and Antoni Andreu (2001) presented a paper on truss geometrical parameter optimization and carried extensive research on shape and cross-section optimization of a truss. Weniyarti Bt. Yunus (2005) presented a paper on investigation on the effects of different truss shapes. The study was done on the 46 types of different candidate truss shapes using pipe sections (Hollow and Circular Section). Max Hultman (2010) presented a paper on weight optimization of steel trusses by a using genetic algorithm. He has carried out size, shape and topology optimization. Jeffrey Smith and Jessica Hodgins (2002) presented a paper on creating models of optimized truss structures and have carried out Computational Geometry and Object Modelling. Non-linear optimization was used for a complex and common category of buildings. Katsuyuki Suzuki and Noboru Kikuchi (1991) presented a paper on homogenization method in shape optimization and carried out structural optimization on wide range attention in computer aided design. U. Kirsch and B. H. V. Topping (1992) presented a paper on minimum weight design of structural topologies and presented a design procedure for optimizing structural topologies. The design variables are the member sizes and the constraints are related to stresses, displacements, and bounds on the variables. D.Wang, W.H. Zhang and J.S. Jiang (2002) presented a paper on the method of evolutionary node shift for the optimization of truss shapes for weight minimization. Multiple load cases were analysed and the structure was subjected to multiple displacement constraints. Ali Ahrari and Ali A.Atai (2013) presented a paper on fully stressed design evolution strategy and proved that fully stressed design is suitable method for design of structure. Optimality is derived on the usage of trusses. Surya N. Patnaik and Dale A. Hopkins (1998) presented a paper on a fully stressed designed truss. Optimality is achieved through fully stressed design. Analytical and graphical methods were employed; this design is extended to displacement constraints and can also be extended to non truss type structures. Bo Ping Wang (1992) presented paper on fully stressed statically indeterminate trusses. Single load condition was employed and varying cross section area was used. Minimum weight was computed for all the trusses and linear programming was used. Hu Ding Zhong (1983) presented a paper on a superstatic truss structure. Fully Stressed design was used and optimal structure was designed for different loading conditions. Relationship between the number of load conditions and the redundant forces in a superstatic truss without sick members was obtained.

In this study, STAAD.Pro has been used for fully stressed design of Warren trusses. For this fully stressed design of Warren trusses, 9 load cases have been considered and 9 types of Warren trusses were used with varying span and parameters resulting in the formulation of 81 cases and for each distinct load case optimized truss is found and its Steel Take-Off is evaluated. The

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study can be further analysed to see thee best suited span and height for the given load condition to have the most economical truss that is the truss having the least steel take-off.

II. STRUCTURAL MODELLING AND ANALYSIS

Nomenclature of the members used for analysis is mentioned in Figure 1. Modelling of the truss is shown in Fig.1. Properties of the trusses are given in Table I. Varying the values of loads A, B, and C, 9 load cases are generated and given in Table 2. The truss is a symmetrical one and there are only 5 independent members (Figure 2)

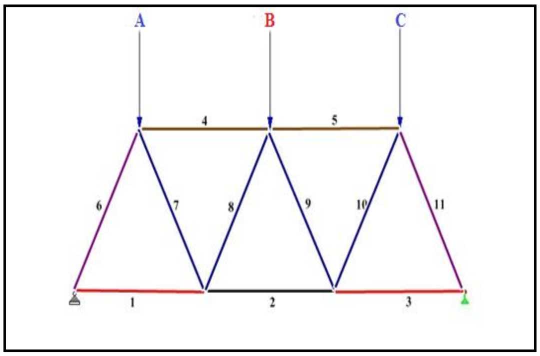

Figure 1 Modelling of Truss

Table 1 Properties of Warren Truss

Sr.	Parameter	Value
1	Members	11
2	Material	Steel
3	Modulus of Elasticity	200 GPa
4	Poisons Ratio	0.25
5	Density	7800 kg/m³
6	Supports	1 End Pinned
		1 End Roller

Table 2 Load Cases for Trusses

LOAD	LOAD	LOAD	LOAD
1.	100	100	100
2.	100	150	100
3.	100	200	100
4.	150	100	150
5.	150	150	150
6.	150	200	150
7.	200	100	200
8.	200	150	200
9.	200	200	200

Table 3 Geometrical Parameters of Trusses Used for Optimisation

CA	SPAN	HEIGHT (m)
1.	6	2
2.	6	3
3.	6	4
4.	7	2
5.	7	3
6.	7	4
7.	8	2
8.	8	3
9.	8	4

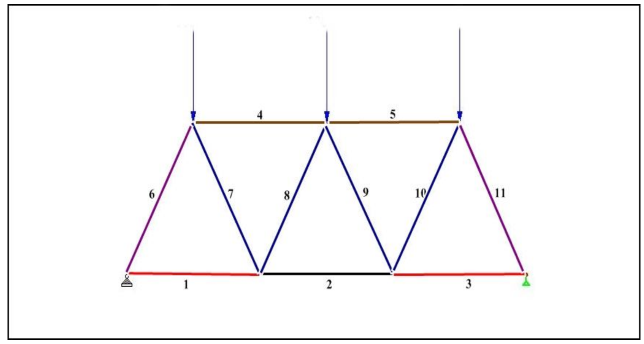

Figure 2 Symmetry of Warren Truss

III. FULLY STRESSED DESIGN

The target stress of truss members is considered as 100 MPa. Based on FSD concept, cross sectional area of truss members is given by-

$$F = A_1 \times \sigma_1 = A_2 \times \sigma_2 \quad (1)$$

$$\text{Hence} \quad A_2 = (A_1 \times \sigma_1)/\ \sigma_2 \quad (2)$$

Where F is member force; A_2 is new area of the member, A_1 is previous area of member, σ_1 is stress in previous iteration and σ_2 is target stress. In this way new cross sectional area are obtained iteratively and the analysis of the stress is done through STAAD.Pro. This table was prepared for each distinct case with a specified loading for example Table IV was made for loading condition no.1 with a span of 6m and height of 2m.In all 81 such tables were to be made for the computation of Steel Take-Off for each case.

Table 4 Steel Take-Off for load case 1 and Geometrical Parameters 1 (6m Span and 2m Height)

MEMBER	DIAMETER	AREA OF	VOLUME
1	0.033	0.000855	0.001992
2	0.043	0.001451	0.003381
3	0.033	0.000855	0.001992
4	0.038	0.001134	0.002642
5	0.038	0.001134	0.002642
6	0.047	0.001734	0.004006
7	0.027	0.000572	0.001321
8	0.027	0.000572	0.001321
9	0.027	0.000572	0.001321
10	0.027	0.000572	0.001321
11	0.047	0.001734	0.004006

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Table 4 was made for loading condition no.1 with a span of 6m and height of 2m.Total volume of the steel used i.e. V used is 0.025947m^3 and Steel Take Off is 202.3865kg.Using similar approach 9 Warren Trusses were analysed for this loading condition No.1 and and the graph was plotted .
Same procedures are adopted for other loading condition and the graphs are plotted from figure 3 to figure 11

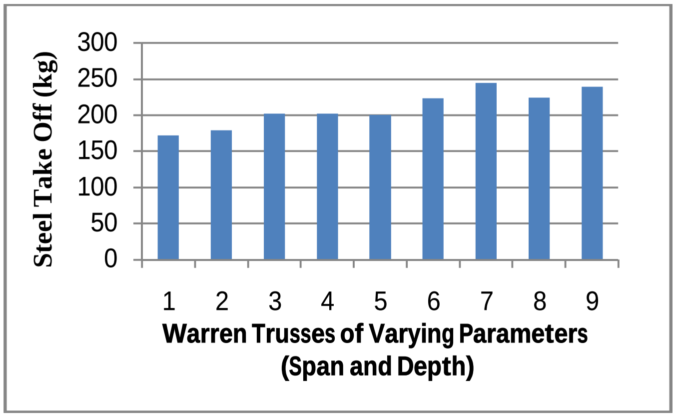

Figure 3 Steel Take-Off for Load Case 1

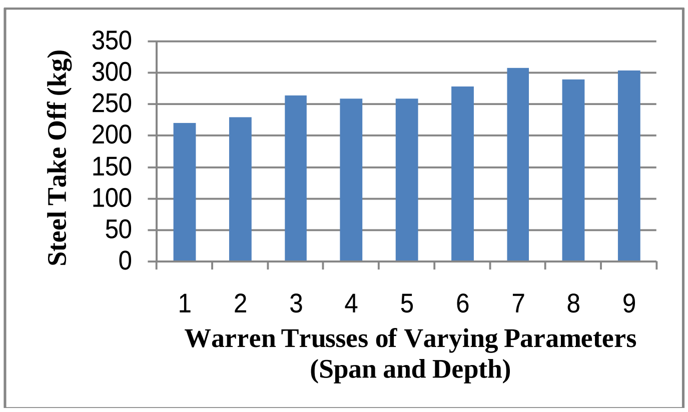

Figure 4 Steel Take-Off for Load Case 2

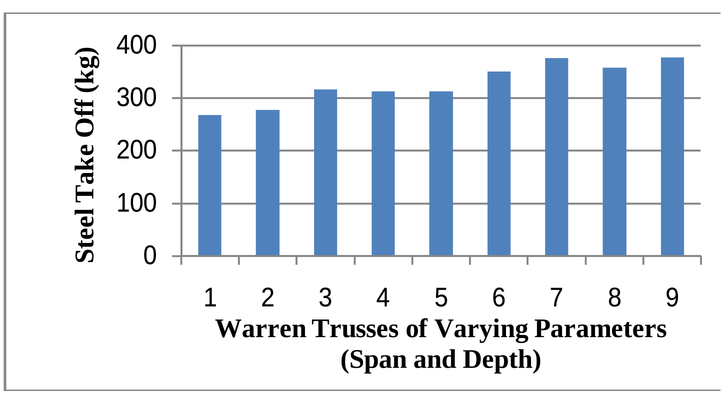

Figure 5 Steel Take-Off for Load Case 3

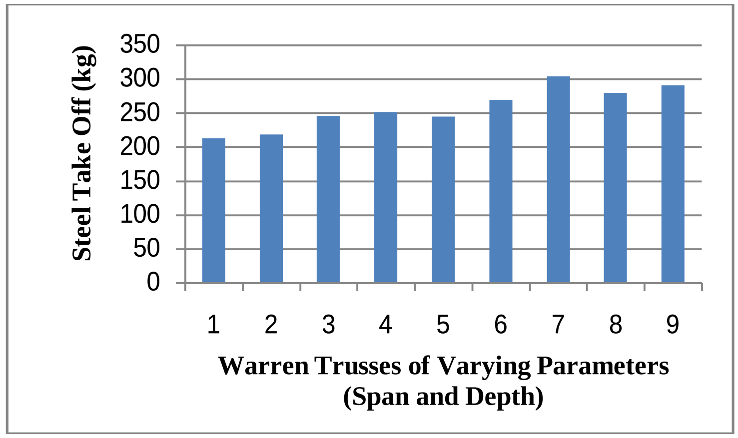

Figure 6 Steel Take-Off for Load Case 4

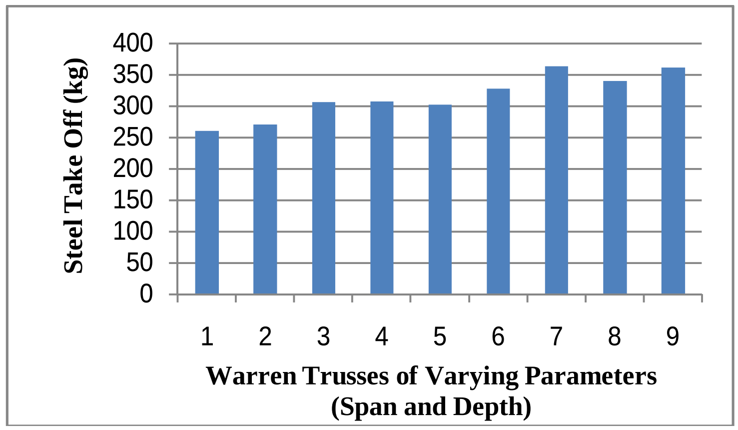

Figure 7 Steel Take-Off for Load Case 5

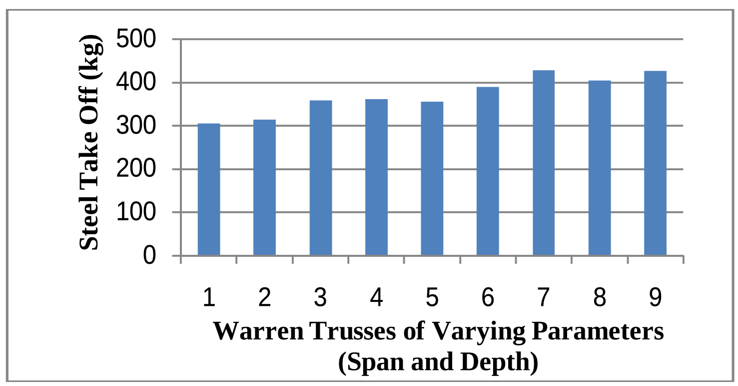

Figure 8 Steel Take-Off for Load Case 6

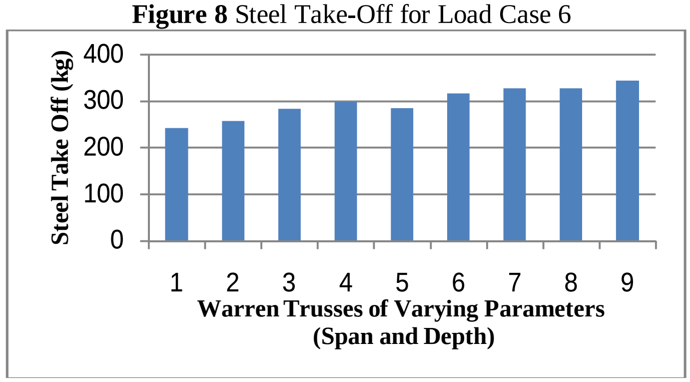

Figure 9 Steel Take-Off for Load Case 7

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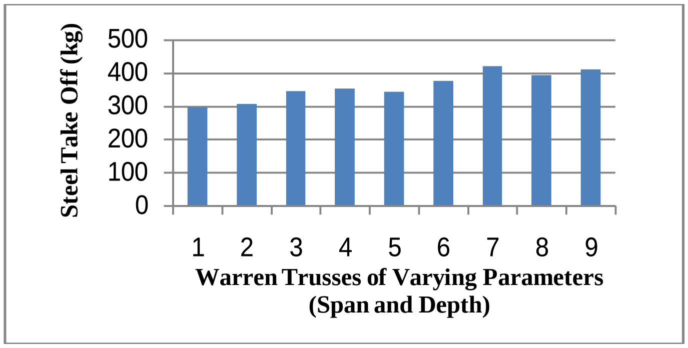

Figure 10 Steel Take-Off for Load Case 8

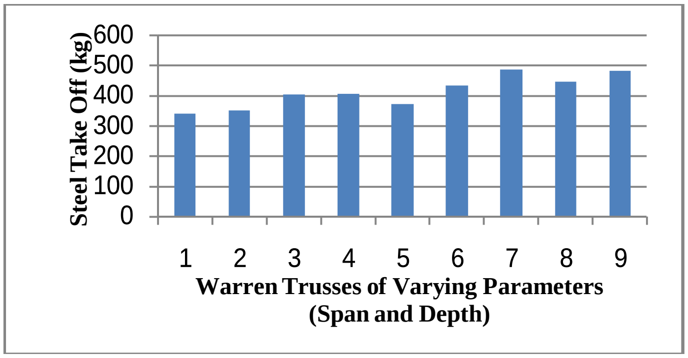

Figure 11 Steel Take-Off for Load Case 9

IV. CONCLUSIONS

Table 5 Weight Corresponding to Various Warren Trusses

NO	Steel Take-Off (kg) CORRESPONDING TO VARIOUS OPTIMISED WARREN TRUSSES								
	6X2	6X3	6X4	7X2	7X3	7X4	8X2	8X3	8X4
1	172	179	201	202	200	223	245	224	239
2	220	229	264	259	258	278	307	289	303
3	267	277	316	312	313	350	375	357	377
4	213	218	245	251	244	268	304	279	290
5	260	271	305	307	302	327	362	339	361
6	306	315	359	361	356	390	428	405	427
7	242	258	283	299	285	317	328	328	344
8	298	308	345	354	343	377	420	393	412
9	341	352	405	408	373	435	488	446	483

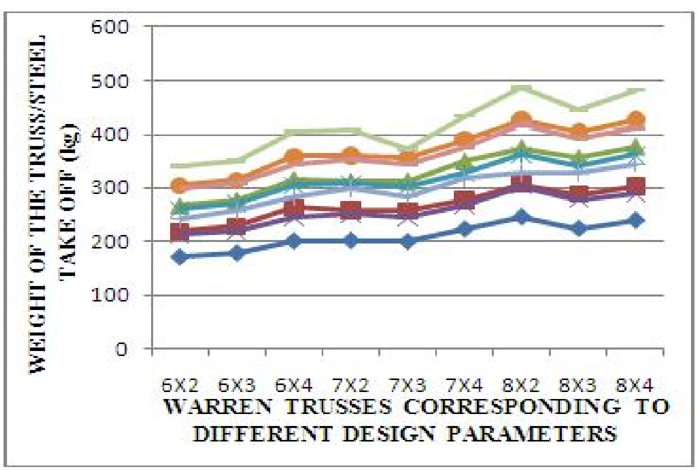

Figure 12 Graph obtained for All Loading Conditions for Different Warren Trusses

From the table 5 we examine the steel take-off of various truss structures obtained through repeated iterations and having a constant stress of 100MPa in each member.

We notice that the weight of the structure does not always increase with the increase in span or height. There are various cases such that when we take the warren truss of 7m span the optimum weight for loading case 1 comes out to be 200kg and the optimum structure is 7m span and 3m height. But for the same loading condition for a 6m span the optimum weight is 172kg and the optimum structure is obtained when the span of the truss is 6m and 2m height. Hence it is always essential to compute these optimisation processes by the design engineer for the computation of best height and span combination for saving the material as well as overall economy of the structure.

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