International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-3, Special Issue-1, April-2015
Fifth National Conference on Innovative Practice in Construction Waste Management (IPCWM'15) On 8th & 9th April, 2015
Organized by Department of CIVIL Engineering, Sri Ramakrishna Institute of Technology, Coimbatore, India

Optimization of Steel Truss Using Staad Pro

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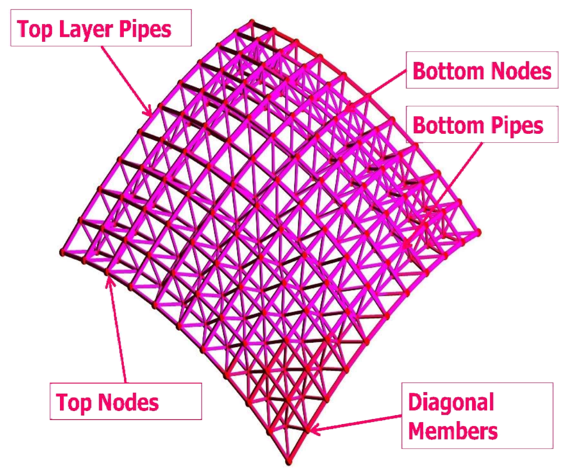
ABSTRACT
This project deals with optimization of a steel space truss. Optimization is a process of subjecting all members present in the structure to its maximum usage thereby ensuring the utilization ratio of each and every element to be above 80%. It is to be noted that the structural properties should not be compromised. The structure has to be made of limit state design and should be a simply supported roof. Optimization of such a truss has been made possible by two approaches for varying the sections of the truss. Based on the analysis made on the results obtained from these trials, the optimal solution of the model is arrived. This report briefly explains the approaches, procedure and result analysis of the space truss optimization process. By using steel structure we can speed up the project, increase the scrap value, reduce foundation block cost and increase the column free working space. Optimizing a steel structure can make the steel structure more efficient and economical.

1. INTRODUCTION
In space truss the predominant forces are compression and tension. There would not be any forces due to couples/ Moments. So the members in the entire space truss will be designed only for axial forces. Skeleton, three dimensional truss works consisting of pin connected bars are called space trusses. They are characterized by hinged joints with no moments or torsion resistance. All members carry only axial compression or tension. A space truss or space truss structure utilizes a three-dimensional truss to resist lateral forces. Unlike a normal truss, in which horizontal, vertical, and diagonal members work together on a single plane, a space truss uses diagonal connections which branch outside of the plane. A space truss usually looks like several interlocking pyramidal outlines.

2. CAD MODELLING
The entire modeling was done on ACAD of span 6.2mX6.2 m. the top layer was established by dividing them into checks of 0.66mX0.66m. Every node was distinguished by introducing 3D spheres at them the members were introduced with 3D pipes. Since the layer is curving the UCS has to be carefully shifted to the checks to locate their geometrical center. Then each set of corner nodes of a check was connected convergent to a single node which will be exactly at the geometrical center of the check at 1.5m below it. Such was done for the remaining checks and these nodes at the bottom become the base for the bottom layer. By connecting these nodes the lower layer is established. As same as the top layer the bottom layer node were also provided with spheres and pipes. Thus the entire model was created using ACAD. The generation of model can be better understood from the figure.



Advantages of Space Truss

- They are light, structurally efficient and use materials optimally. It can be designed in such a way that the total weight comes between 15 to 20kg/m^2
- It can be built up from simple, prefabricated units of standard size and shape. Hence they can be mass-produced in the factory, can be easily and rapidly assembled at site using semi-skilled labor's.
- The small size components simplify the handling, transportation and erection
- They are an elegant and economical means of covering large column free spaces.
- They allow great flexibility in designing layout and positioning of end supports.
- Services such as lighting, air conditioning etc., can be integrated with space structures.
- The use of complicated and expensive temporary supports during erection is eliminated.
- They posses great rigidity and stiffness for a given span/depth ratio and hence are able to resist large concentrated and unsymmetrical loading. Local overloading can be taken care by built-in reserve strength. They do not collapse locally.

3. COMPONENTS OF SPACE TRUSS

- Axial members which are preferably ***tubes***
- ***Connectors*** (Mero nodes) which join the members together
- Bolts connecting members with nodes

4. OPTIMIZATION PROCESS

Optimization

Structural optimization problems involve searching for the minimum of a stated objective function, usually the structural weight. This minimum design is subjected to various constraints with respect to performance measures, such as stresses and displacements, and also restricted by practical minimum cross-sectional areas or dimensions of the structural members or components. The design variables are varied on following a pattern to make the optimization process easier and systematic. The process of optimization brings out the maximum utilization from most of the members of any structure. As a first step the members of the truss were grouped into 5 groups based on their utilization ratios. And then the optimization of this space truss was done by manually by varying the sections of the truss and collecting their results to figure out the best optimized solution. However iterative trials can be done infinitely. Hence the optimization process was made possible by following two types of approaches separately for grouped and ungrouped models.

- Keeping the outer diameter of the pipe sections constant and varying the thicknesses for each.
- Keeping the thickness constant and varying the outer diameters for each.

Thus the results for all trials were compiled into graphs to make the result analysis easier and the configuration with maximum utilization, less weight, minimum deflection was arrived.

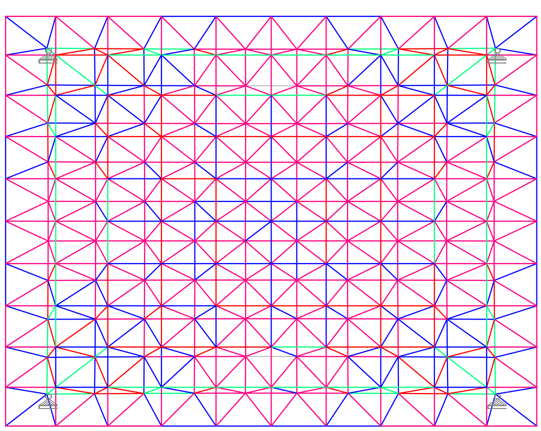
Utilization Ratio

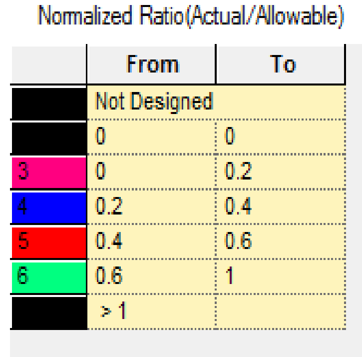
Utilization ratio of a member can be defined as the ratio of load carrying capacity of the element to the actual load on the element.

$$\text{Utilization ratio} = \frac{\text{actual load on an element}}{\text{Load carrying capacity of the element}}$$

One of the members from the basic model is chosen and their utilization ratio is arrived manually and checked with the utilization ratio from STAAD PRO.

Grouping of Truss Diagram





Normalized Ratio(Actual/Allowable)

	From	To
	Not Designed	
	0	0
3	0	0.2
4	0.2	0.4
5	0.4	0.6
6	0.6	1
	> 1	

Figure 1. Utilization Ratio Chart Obtained From STAAD PRO

As a first step of optimization, the members of the truss were grouped into 5 groups based on their utilization ratios. Here each color represents each range of utilization percentage as shown in legend of the figure. For example here the pink color represents the members in the range 0 to 20 percentage; blue represents members in the range 20 to 40 percentages; red color represents members in the range 40 to 60 percentages and green color represents the members in the range 60 to 100 percentage.

5. RESULTS OF UNGROUPED MODELS

Some models were worked without grouping i.e. assigning same sections for all the sections at a time and reading their results. This was also done by same constant OD and constant thickness approaches. Their results can be read from following table1 and 2.

Table 1: Constant Thickness and Varying OD Trials

	T					OD					DEFLECTION in mm	WEIGHT (KN/ sqft)	ABOVE 60 % UR
MODEL 1	2					21.3					7.949	4.833	21.875
MODEL 2	2						26.9				6.154	6.235	11.125
MODEL 3	2							33.7			4.812	7.937	4.5
MODEL 4	2								42.4		3.742	10.116	1.5
MODEL 5	2									48.3	3.24	11.593	1.5
MODEL 6		3				21.3					5.588	6.873	13.25
MODEL 7		3					26.9				4.276	8.977	4.5
MODEL 8		3						33.7			3.315	11.531	1.5
MODEL 9		3							42.4		2.561	14.798	1.5
MODEL 10		3								48.3	2.21	17.014	1
MODEL 11			4			21.3					4.433	8.664	9.25
MODEL 12			4				26.9				3.348	11.468	2.625
MODEL 13			4					33.7			2.572	14.873	1.5
MODEL 14			4						42.4		1.972	19.23	1
MODEL 15			4							48.3	1.697	22.185	0
MODEL 16				5		21.3					3.763	10.203	4.875
MODEL 17				5			26.9				2.801	13.709	1.5
MODEL 18				5				33.7			2.13	17.966	1.5
MODEL 19				5					42.4		1.622	23.412	0
MODEL 20				5						48.3	1.391	27.105	0
MODEL 21					6	21.3					3.34	11.493	6
MODEL 22					6		26.9				2.946	15.7	1.5
MODEL 23					6			33.7			1.84	20.808	1
MODEL 24					6				42.4		1.39	27.343	0
MODEL 25					6					48.3	1.188	31.775	0

Table 2: Constant OD and Varying Thickness Trials

	T					OD					DEFLECTION in mm	WEIGHT (KN/ sqft)	UR
MODEL 1	21.3					2					7.966	4.822	21.6
MODEL 2	21.3						3				6.219	6.177	14.75
MODEL 3	21.3							4			4.433	8.664	9.7
MODEL 4	21.3								5		3.763	10.203	6.125
MODEL 5	21.3									6	3.34	11.493	6.1
MODEL 6		26.9				2					5.32	7.213	6.625
MODEL 7		26.9					3				4.768	8.05	5.75
MODEL 8		26.9						4			3.34	11.468	2.625
MODEL 9		26.9							5		2.801	13.709	1
MODEL 10		26.9								6	2.446	15.7	1.5
MODEL 11			33.7			2					4.812	7.937	4
MODEL 12			33.7				3				3.717	10.282	1.5
MODEL 13			33.7					4			2.546	15.024	1.5
MODEL 14			33.7						5		2.13	17.966	1.5
MODEL 15			33.7							6	1.84	20.808	1
MODEL 16				42.4		2					3.742	10.116	1.5
MODEL 17				42.4			3				2.871	13.191	1.5
MODEL 18				42.4				4			1.972	19.23	1
MODEL 19				42.4					5		1.622	23.412	0
MODEL 20				42.4						6	1.391	27.105	0

6. RESULTS OF GROUPED MODELS

Constant Thickness and Varying OD Trials

GROUPED			
CONFIG	DEFLECTION(mm)	WEIGHT(KN)	UR %
2mm	4.793	5.958	2.5
3mm	3.309	8.562	0
4mm	2.574	10.915	0
5mm	2.139	13.018	0
6mm	1.855	14.871	0

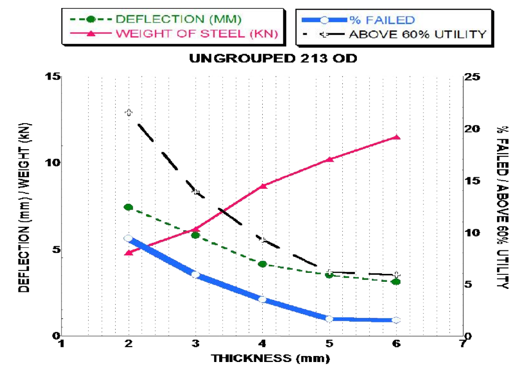
For every configuration, the thickness of members were kept constant and the ODs were varied for each group i.e. for 2mm thickness, the group 1 members were assigned with OD 21.3mm, for group 2, 26.9mm and similarly for group 3,4,5 with 33.7mm, 42.4mm, 48.3mm respectively and such for all thicknesses.

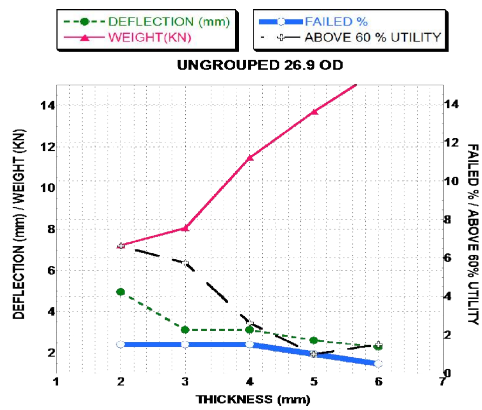
7. GRAPHICAL RESULTS AND DISCUSSIONS

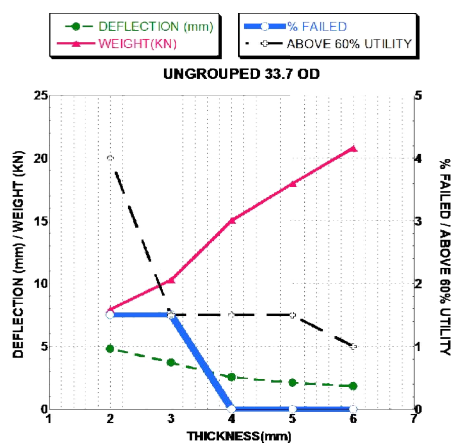
Results of Ungrouped Models

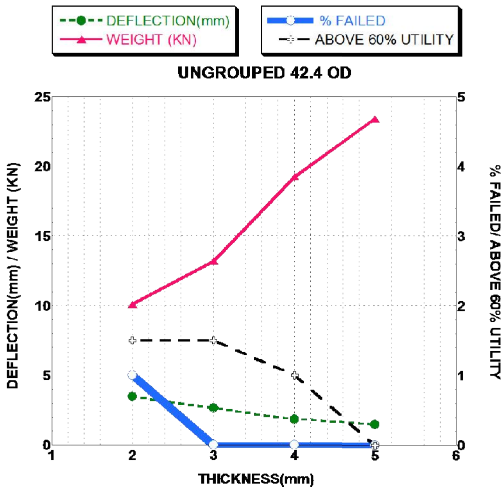
Constant OD and Varying Thickness Trials

Graph 1 gives a view of set of models worked with OD 21.3mm and various thicknesses providing same section at an instance for all members irrespective of groups. Thus graphs 2, 3 and 4 also represent similar sets with OD 26.9mm, 33.7mm and 42.4mm. Analyzing their results from all five graphs, 26.9mm OD was found to produce the best optimized results considering the lesser weight, improved utilization and reduction in deflection. It is to be noted that the optimum results are obtained only for the 3mm thickness from above graphs 1 to 4.





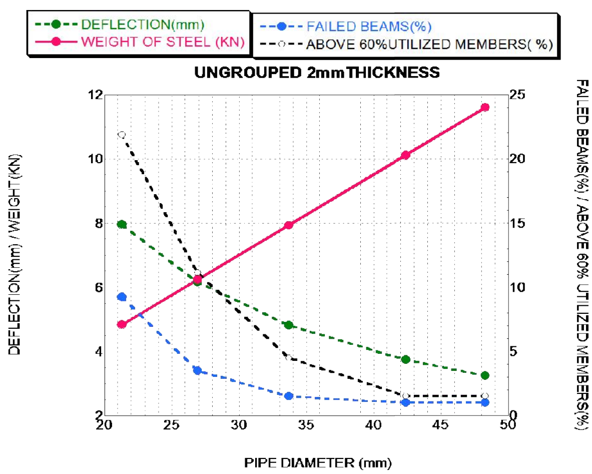


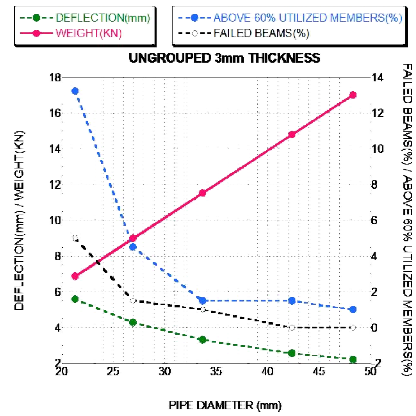


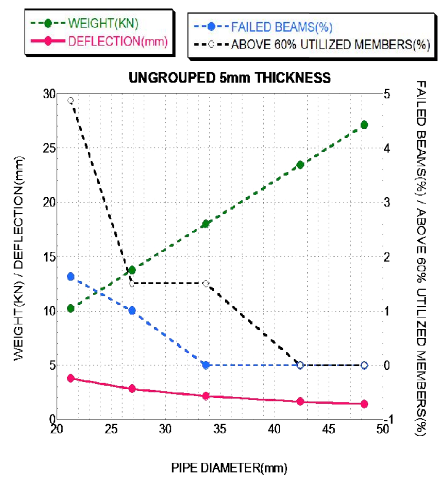
Results of Ungrouped Model Type 1 Optimization

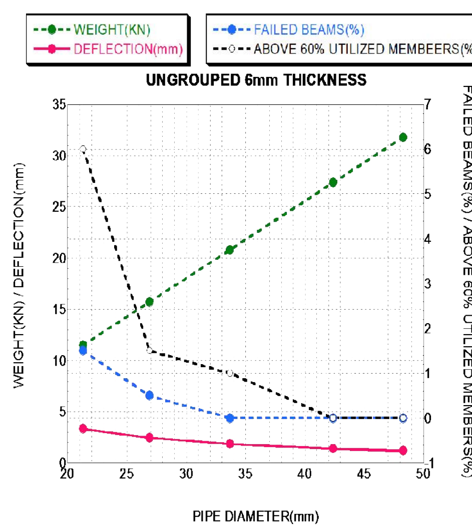
Constant Thickness and Varying OD Trials

The following graphs are tried for thicknesses 2mm, 3mm, 4mm, 5mm, and 6mm respectively. The results obtained by trying various ODs like 21.3mm, 26.9mm, 33.7mm, 42.4mm and 48.3mm were analyzed to arrive the best performing model thickness. Thus 3mm was found to be the optimum model.







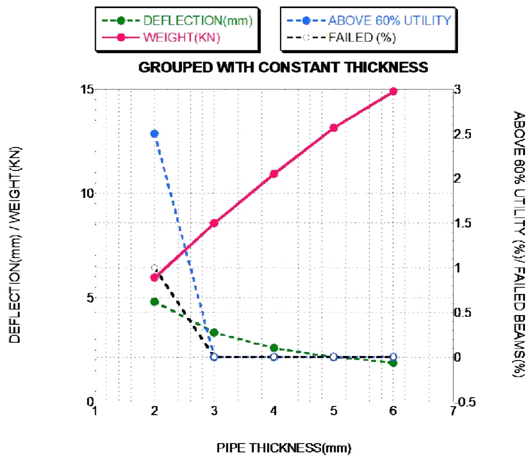


Results of Ungrouped Model Type 2 Optimization

Results of Grouped Models

Constant Thickness and Varying OD Trials

Graph 3 gives the results of grouped trials by keeping the thicknesses constant and varying the ODs similar to graph1. This concludes 3mm thickness to produce maximum performance.

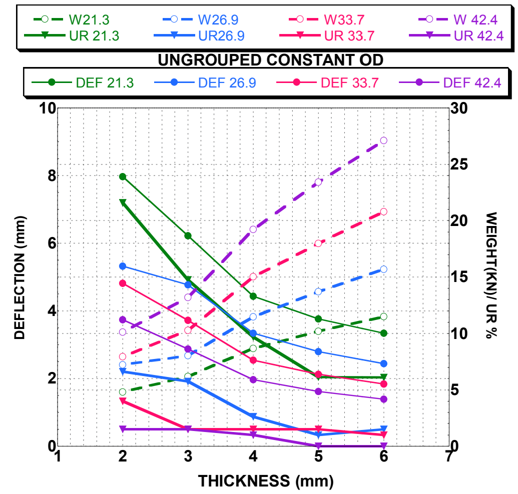


8. RESULT ANALYSIS

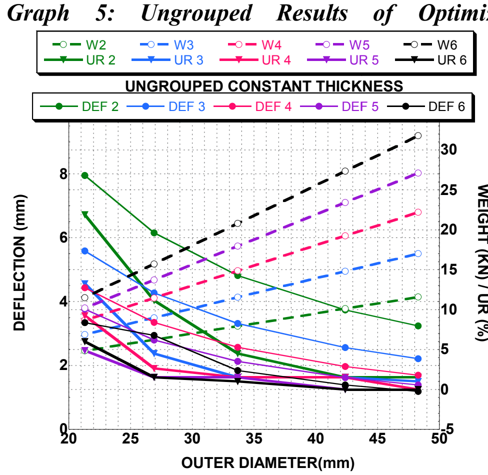
The graphical results gave number of conclusions for each set of results. Hence to make the comparison wider the results were put into four graphs.

- Ungrouped results of optimization 1.
- Ungrouped results of optimization 2.
- Grouped results of optimization 2.

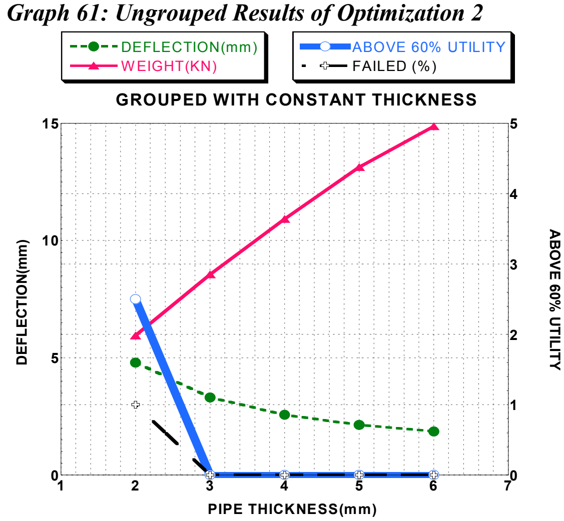
These four graphs are shown below in the above order as graph 5, 6, and 7. The results were analyzed such a way each set was discarded for a valid reason such as higher steel consumption, high deflection and minimum utilization of members. In such way the most optimum and feasible solution of the space truss was arrived. In graphs 5 the results of 21.3mm OD was discarded for the reason that it had numerous failed members. Thus the graph 6 has the results of 5 grouped models excluded for the aspect of utilization ratio. Comparing the available results the optimum results were found to be the OD 26.9mm.
Similarly the results of models with constant thickness approach were also analyzed and the result was found to be 26.9mm OD.
Thus the graphs 6 and 7 were also analyzed in similar pattern. The results of OD 42.4 mm and 21.3 mm were excluded for the aspect of weight and deflection respectively as shown in graphs. Comparing the available results the optimum result was easily arrived as 26.9mm OD and 3mm thickness as in graph .The same procedure was repeated for the graphs of constant thickness approach. The result of 2mm thickness was discarded for possessing maximum deflection. The results of OD 5mm and 6 mm were discarded for the aspect of weight of steel in graphs successively. Followed by excluding of 4mm thickness results as comparatively the 3mm thickness results seemed to be better which can be referred from graphs and the final result stuck to 26.9mm OD and 3mm thickness as in constant OD approach.



Graph 5: Ungrouped Results of Optimization 1



Graph 61: Ungrouped Results of Optimization 2



Graph 7: Grouped Results of Optimization 2.

9. CONCLUSION

The conclusion is made by identifying the optimum solution from the above said process of result analysis. It is pertinent to be noted that we were getting members with 26.9mm OD and 3mm thickness as the best optimistic model by the two approaches handled. Thus arrived solution is the configuration with OD 26.9mm and thickness 3mm with following properties.

Deflection= 4.678 mm
Weight = 8.05 KN (1.94 Kg per Sqft)
Number of Members above 60 % utilization = 112
Number of failed beams = nil.

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