Optimization of 2-D Steel Truss by Grid Search Method

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Abstract - Optimization of truss structures for finding optimal cross sectional size and configuration of 2-D trusses to achieve minimum weight is carried out by Grid search method. Function evaluation at various grid points by Excel STAAD VBA interface. For geometry variation Truss heights is in outer loop, no of bays is in inner loop. Generates basic information for geometry like node no, node coordinate, member no, member incidence. Create separate input like loading is different for each geometry and common input like member property, support condition, member specification, and steel design command. Excel creates a separate Staad file for and pass particular information related to geometry required for analysis and design. By this procedure probably optimal solution is getting for 18m span with Pratt truss configuration.

Key Words – Optimization by Grid search method, Excel STAAD VBA interface, Size and Configuration optimization.

I. INTRODUCTION

The basic principle of optimization is to find the best possible solution under given circumstances. The term optimal structure is very uncertain. This is because a structure can be optimal in different aspects. These different aspects are called objectives, and may for instance be the weight, cost or stiffness of the structure.[1] The solution of problem depends on various factors like objective function formulation, constraint formulation, method adopted, starting point, step size etc. Basically there are three different ways of truss optimization. (1) Sizing Optimization, (2) Configuration Optimization, (3) Topology Optimization.

- Sizing optimization is the simplest form of structural optimization. The shape of the structure is known and the objective is to optimize the structure by adjusting sizes of the components.[1]
- As with sizing optimization the topology (number of holes, beams, etc.) of the structure is already known when using shape optimization, the shape optimization will not result in different shape. In shape optimization the design variables can for example nodal coordinates, Member incidences.[2]
- The most general form of structural optimization is topology optimization. As with shape and size optimization the purpose is to and the optimum distribution of material. With topology optimization the resulting shape or topology is not known, the number of holes, bodies, etc., are not decided upon. To solve this problem it is discretized by using finite element method and dividing design domain in to discrete element (mesh).[3]

Basic approach is utilizing both Sizing optimization and Configuration optimization by Grid Search method. Grid search method is versatile for discrete objective function and to get trend. It is useful when one can evaluate objective function very quickly at various grid points. This can possible in case of truss like generate no. Of geometries in M. S. Excel, pass this geometry information to structural analysis and design software (e.g. STAAD Pro), perform analysis and steel design in the same software, call software design result and calculate material take off, finally interpret the result.

II. OPTIMIZATION METHOD

Grid search method is setting up suitable grid in design space, evaluate objective function at all grid points and finding the grid point corresponding to lowest function value.[6]

For topology variation change the height of truss and no. of bays along the span. So, grid points are various truss topologies as shown in fig 1.

In this method perform multiple run for batter solution. Initially go for wide range grid means points are not closely spaced. After first run set finer grid near to the solution which got from previous.

Basically this approach is like unconstrained optimization problem but constrains are satisfying by software in the design part of structure.
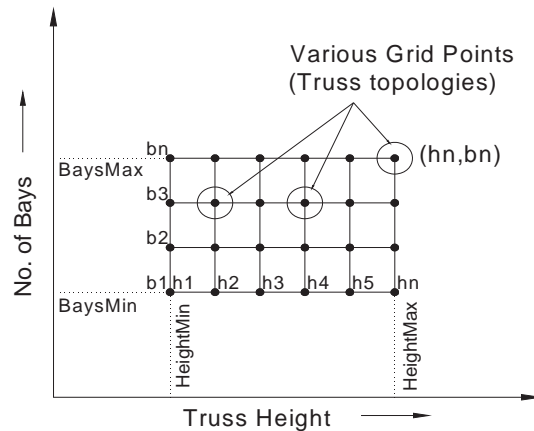

Fig 1 Grid search method for truss

III. OBJECTIVE FUNCTION

Mathematically minimum weight truss optimization problem can be stated as:

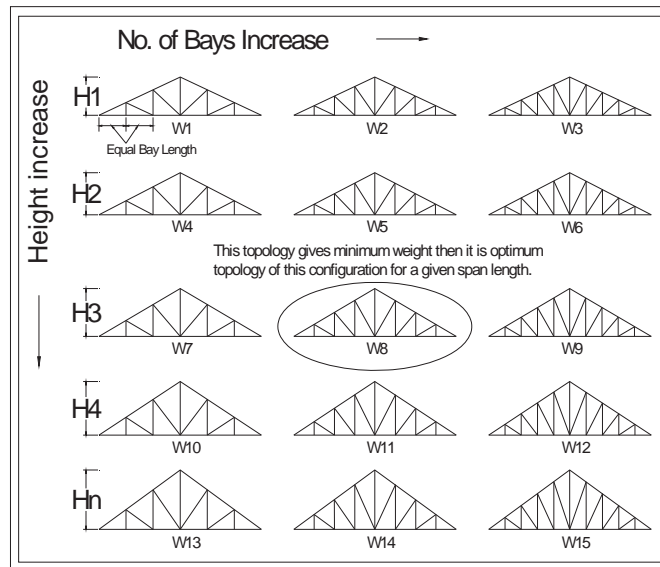$$F(A_e, l_e) = \sum_{e=1}^{n} A_e * l_e * \rho$$

Where

e = Element no.

A = Cross-section area of respective element

L = Length of Member

ρ =Material Density

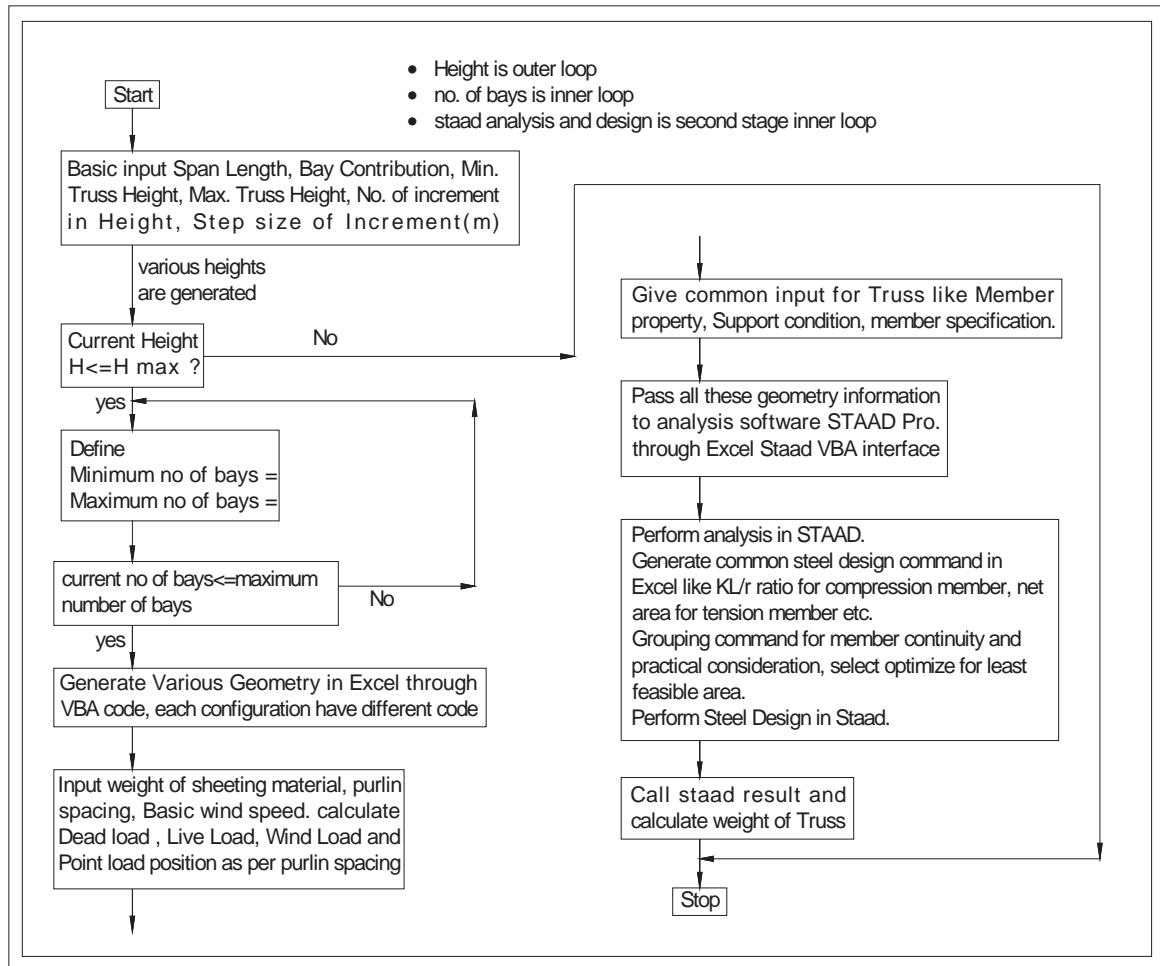**n = Total no. of element in truss**

IV. METHODOLOGY

Two variables are considered for geometry variation, height of truss and no of bays along span. Fig shows the basic work objective.

For each standard configuration few main procedures are coded. These procedures are bunch of many sub procedures. Procedures are sequentially link to each other, each procedure is creates basic input platform for

next procedure. These procedures are written in Excel through VBA language. Basic iteration cycle is shown in fig.

Start

- Height is outer loop
- no. of bays is inner loop
- staad analysis and design is second stage inner loop

Basic input Span Length, Bay Contribution, Min. Truss Height, Max. Truss Height, No. of increment in Height, Step size of Increment(m)

various heights are generated

Current Height H<=H max ?   — No

yes

Define Minimum no of bays = Maximum no of bays =

current no of bays<=maximum number of bays   — No

yes

Generate Various Geometry in Excel through VBA code, each configuration have different code

Input weight of sheeting material, purlin spacing, Basic wind speed. calculate Dead load , Live Load, Wind Load and Point load position as per purlin spacing

Give common input for Truss like Member property, Support condition, member specification.

Pass all these geometry information to analysis software STAAD Pro. through Excel Staad VBA interface

Perform analysis in STAAD. Generate common steel design command in Excel like KL/r ratio for compression member, net area for tension member etc. Grouping command for member continuity and practical consideration, select optimize for least feasible area. Perform Steel Design in Staad.

Call staad result and calculate weight of Truss

Stop

Following procedures are only for particular standard Truss configuration. For other type of truss sequence is same but coding is different. Main procedures are listed below:

1) Generate Geometry of Standard Truss configuration,
Basic concept of this procedure is to generate inputs which are required to create model in Staad pro software like Node no, Node coordinate, Member no, Member incidences. This all geometries are generating in Excel through VBA language from user inputs like initial height of truss, how many variation in height, step size for variation, initial no. of bays, and maximum no. of bays.
Each worksheet is valid only for particular standard truss configuration because VBA code follows the relation established by user for particular truss type. These relations are like total number of nodes, total number of members and other tricky relation.

2) Calculate Dead load, Live load and Wind load,
In this procedure calculate dead load and live load for truss. Dead load is calculated from contributory width of truss, unit weight of sheeting material, unit weight of purlin and service load. Live load considered as per IS 875 (Part-2). These loads are applied to top chord member as point load as per purlin spacing.
Calculate wind load in accordance with IS 875 (Part-3) in separate worksheet. This procedure creates primary load case for Staad file in Excel. Considered three primary load case 1.Dead Load (Self weight, Point Load) 2.Live Load 3.Wind Load (as per calculation). Load combination are generates according to IS 800:2007.
3) Create STAAD file from basic input and perform analysis,

Main function of this procedure is pass basic information of truss like Geometry, support condition, material properties (single angle, double angle, channel section, Pipe section, and Tube section), and loading condition to Staad software.
For each geometry a new Staad file is created with following nomenclature:

> File name nomenclature:
> File name is combination of Truss configuration name, Span length, Contributory width, Height of Truss, no. of Bays, Bay spacing (equal spacing).
> File name should be look like this "Pratt truss_ 15_4_2.1_8_equal"

All those information which are required to perform analysis are passed from Excel to Staad software through Staad-VBA command. These commands are listed in Staad software Help.

4) Create steel design command to perform steel design,

Generate steel design command like kL_{eff}/r ratio for compression member, Net area for tension member after deduction of bolt hole, Select optimized for least feasible area, Grouping of member for member continuity.

5) Call STAAD result and result interpretation.

After design material take off are calculated for each geometry, plot the contour and find out the best configuration which gives minimum weight.

V. EXAMPLE PROBLEM

Data consideration and assumption:
> Truss configuration
> Pitched Pratt truss, Span 18m, Bay contribution 6m. Building height is 6m at eaves. Both ends are pinned supported. All members are released for MZ at both ends.
> Dead Load and Live Load
> GI Sheeting = 0.16 KN/m^2,
> Purlin Spacing = 1.4m,
> Fixing and Service = 0.125 KN/m^2,
> Purlin = 0.13 KN/m^2,
> Live Load = 0.75 KN/m^2,
> Edge and crown distance = 0.3m.
> Wind Load
> Basic wind speed = 44 m/s,
> Life of building = 50 years,
> Flat topography.

In example loads are transfer through point load according to purlin spacing. Point load is not acting at node so there is bending in top chord member. All members are released so there is no transfer of moment only shear is transferred. Top chord member are design for both bending and axial. Wind load is calculated for $0°$ degree wind angle.

Four height variations are considered 2.5 to 4m at interval of 0.5m, and four bays variation 8 to 14. Following load cases are considered for analysis and design purpose. Limiting deflection is Span/240 (75mm).

> Primary Load Case
1. Dead Load,
2. Live Load,
3. Wind Load in +ve X,
4. Wind Load in –ve X
> Load Combination
1. 1.5 DL + 1.5 LL
2. 1.2 DL + 1.2 LL + 0.6WL +veX
3. 1.2 DL + 1.2 LL + 0.6 WL –veX
4. 1.2 DL + 1.2 LL + 1.2 WL +veX
5. 1.2 DL + 1.2 LL + 1.2 WL –veX

6. 1.5 DL + 1.5 WL +veX
7. 1.5 DL + 1.5 WL -veX
8. 0.9 DL + 1.5 WL +veX
9. 0.9 DL + 1.5 WL -veX
> Load Combination for Deflection
1. 1.0 DL + 1.0 LL
2. 0.8 DL + 0.8 LL + 0.8 WL +veX
3. 0.8 DL + 0.8 LL + 0.8 WL –veX
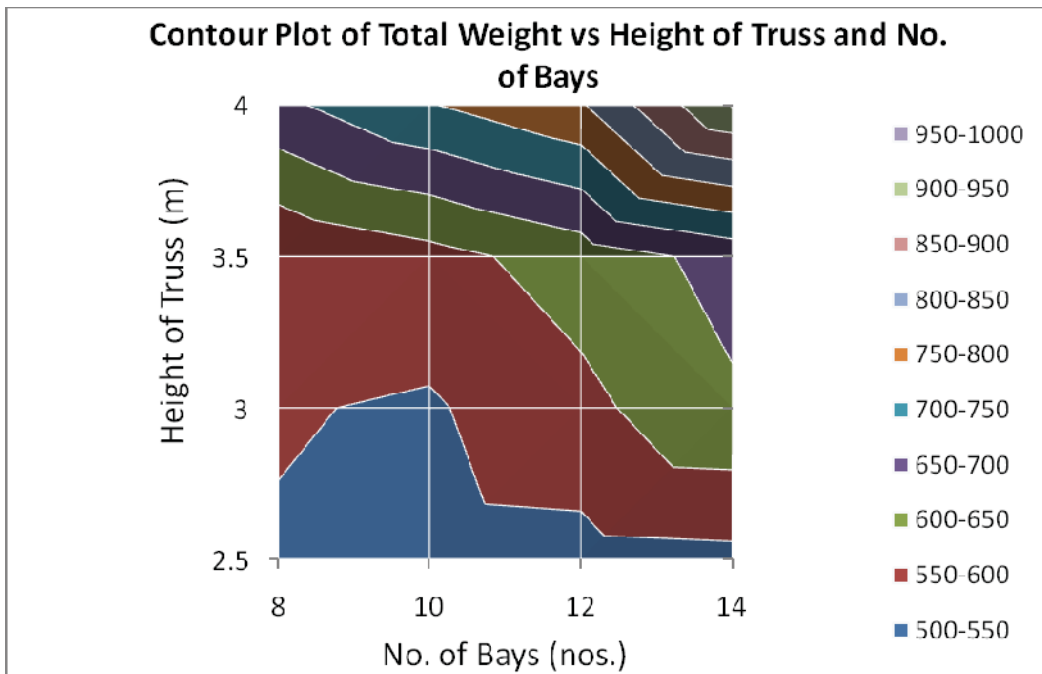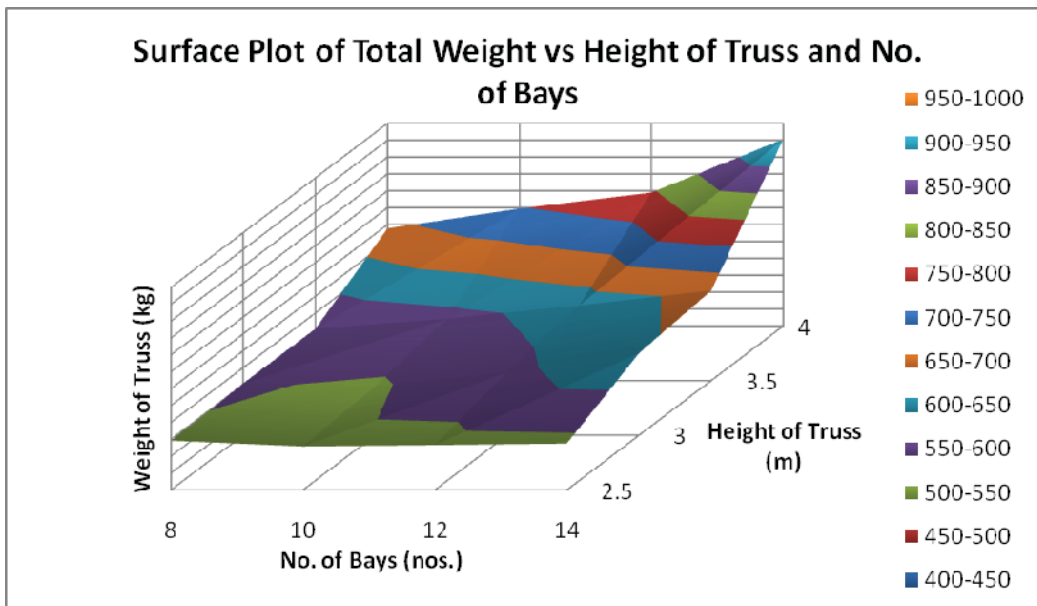4. 1.0 DL + 1.0 WL +veX
5. 1.0 DL + 1.0 WL –veX

VI. RESULT

For different geometry material take off (kg) is tabulated and deflection (mm) is mentioned in parenthesis.
From table it can be seen that minimum weight of truss is 529 kg, corresponding to 2.5m height and 10 no of bays. Surface plot and contour plot are shown if fig. Surface plot shows the nature of the objective function.

Table: Steel take off (kg) and deflection (mm)

No of Bays (nos.) Truss Height (m)	8	10	12	14
2.5	546 (17.20)	529 (19.92)	533 (21.47)	538 (21.38)
3	554 (13.82)	544 (15.68)	587 (15.29)	643 (15.19)
3.5	555 (11.90)	583 (13.77)	623 (15.70)	667 (16.98)
4	689 (10.07)	747 (12.35)	795 (13.84)	953 (10.26)

Surface Plot of Total Weight vs Height of Truss and No. of Bays

Contour Plot of Total Weight vs Height of Truss and No. of Bays

VII. CONCLUSION

Results are tabulated for widely spaced grid points, in second iteration set fine grid near 2.5m height to get better solution. In this example connection cost is not considered, if we get same result for different no of bays then consider connection cost while choose the solution.

With better automation this method is apply to various truss configuration like Howe truss, N-type truss, Fink truss and find out optimal solution.

Here results are shown for 18m span. For different span optimal solution occur at different height. So one can go for various span lengths and give generalise height in terms of span length.

One can extend this work for unequal bays spacing, means near support bays are closely spaced compare to middle span. Initially set criteria for bay spacing according to no. of bays and incorporate it in the geometry.

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