Design of Large Span Roof Truss under Medium Permeability Condition

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Abstract

RCC structures for covering a larger area become heavy and hence uneconomical. In such cases, steel roof trussed building are used and become economical due to its lighter weight. A 20 metre span steel roof truss is considered in the present study. IS:875 (Part I, II and III) have been considered in the calculation of loadings on roof truss. Finally the analysis as well as design of the roof truss has been carried out by STAAD Pro V8i. Limit State Method is adopted here.

Keywords: Large Span Roof Truss, Dead Load (DL), Live Load (LL), Wind Load (WL), STAAD Pro V8i, AUTO CAD, IS 800 and IS: 875 (Part I, II & III)

I. INTRODUCTION

Truss is a pin jointed structure. King and Queen post truss, pitched Pratt truss, pitched Howe truss, Fan truss, pitched Fink truss, Trapezoidal truss, etc. are used in roof trusses. Fink truss has been considered in our studies. The roof truss is made of Rolled Steel Joists. Fink truss is generally used for large span. The analysis of a large span roof truss is tedious and time consuming. Hence STAAD.Pro V8i is used for analyzing and designing the roof truss.

II. PROBLEM STATEMENT

A suitable fink roof truss is to be designed for covering an industrial building (45 metre long and 20 metre wide). The building is to be built in New Delhi. Medium permeability condition is used in this study. The trusses are to be spaced at 3 metre intervals. Asbestos cement (AC) sheet is used as roof coverings.

III. GEOMETRY OF ROOF TRUSS

Span of roof truss = 20 metre  
Spacing of truss = 3 metre  
Pitch of truss = ¼  
Height of truss = 1/4 x 20 = 5 metre  

A roof truss has been modeled accordingly and is shown in figure 1.  

Let α be the inclination of the roof with the horizontal,  
\[ \tan \alpha = \frac{5}{10} = 0.5, \alpha = 26.57^0. \]

Slope Length = \[ \sqrt{5^2 + 10^2} = 11.181 \text{ metre}. \]

Length of each panel \[ L_0U_1, U_1U_2, U_2U_3, U_3U_4, U_4U_5, U_5U_6, U_6U_7, U_7U_6, U_6U_5, U_5U_4 \] = 11.18 metre.  

Length of each panel = 2.795 x cos 26.57^0 = 2.5 metre.

IV. CALCULATION OF LOADINGS ON ROOF TRUSS

A. Dead Load (DL):

IS: 875 (Part I) – 1987 has been considered to calculate dead load.  

Weight of sheet = 0.2 kN/m²  
Weight of bracing = 0.015 kN/m²  

Self-weight of roof truss = \[ \frac{\text{Span}}{3} \times 10 \text{ N/m}^2. \Rightarrow \frac{20}{3} \times 10 \text{ N/m}^2 = 0.116 \text{ kN/m}^2 \]

Weight of purlins = 0.15 kN/m²  
Total dead load (DL) = 0.481 kN/m²  
The dead loads are shown in figure 2.  
Dead load at each intermediate node, \[ W_1 = 2.5 \times 3 \times 0.331 = 3.608 \text{ kN}. \]
Dead load at end nodes = \( \frac{W_1}{2} = \frac{3.608}{2} = 1.804 \text{ kN} \)

Considering the weight of duct and false ceiling as 0.25 kN/m²,
Dead load at nodes 2, 3, 4, 5 and 6, \( W_7 = 3.5 \times 3 \times 0.25 = 2.625 \text{ kN} \).
Dead load at nodes 1 and 7 = \( \frac{W_7}{2} = \frac{2.625}{2} = 1.3125 \text{ kN} \).
Dead load is Load Case 1.

**B. Live Load:**

IS: 875 (Part II) – 1987 has been considered to calculate live load. No access is provided in the roof except for repair and maintenance.

Live load on roofs is taken as 0.75 kN/m² of plan area.
For roof of slope \( \alpha = 26.57^0 \), live load = \( [750 - 20 \times (26.57-10)] \text{ N/m}^2 = 418.6 \text{ N/m}^2 = 0.4186 \text{ kN/m}^2 \).

The live loads are shown in figure 3.

Live load at each intermediate node, \( W_2 = 3.14 \text{ kN} \).
Live load at end nodes = \( \frac{W_2}{2} = \frac{3.14}{2} = 1.57 \text{ kN} \).
Live load is Load Case 2.

**C. Wind Load:**

IS: 875 (Part III) – 1987 has been considered for the calculation of wind loads.
Fig. 3: Live Load at Nodes

Fig. 4: Wind Load at Nodes (Wind Perpendicular to the Ridge)

Fig. 5: Wind Load at Nodes (Wind Parallel to the Ridge)
Assuming the life of the industrial building to be 50 years and the land to be flat and surrounded by small buildings,
k_1 = probability factor or risk factor = 1 [for general buildings and structures]
k_2 = terrain, height and structure size factor = 0.998 [for terrain of category 3 and building of class B of 12 metre height]
k_3 = topography factor = 1 [For flat topography]

Design wind speed, \( V_z = V_b \times k_1 \times k_2 \times k_3 \)

\( V_b \) = Basic wind speed at New Delhi, \( V_b = 47 \) metre/second

Design wind speed, \( V_z = 1 \times 0.998 \times 1 \times 47 = 46.906 \) metre/second

Design wind pressure, \( p_z = 0.6 V_z^2 = 0.6(46.906)^2 = 1320 \) N/m² = 1.320 kN/m².

Eave height, \( h = 12 \) m.

Width of building, \( w = 20 \) m.

\[ \frac{h}{w} = \frac{12}{20} = 0.6 \quad \left( \frac{1}{2} < \frac{h}{w} \leq \frac{3}{2} \right) \]

\( F = (C_{pe} - C_{pi}) \times p_z \times A, \) where

\( C_{pe} = \) external wind pressure coefficient
\( C_{pi} = \) internal wind pressure coefficient.

\( A = \) surface area of structural element = 3 x 2.795 = 8.385 m².

For building having medium permeability, the internal pressure coefficient, \( C_{pi} = \pm 0.5. \)

Slope of roof truss, \( \alpha = 26.57^\circ. \)

The external pressure coefficients, \( C_{pe} \) are calculated and are shown in Table 1 and Table 2.

**Table – 1**

<table>
<thead>
<tr>
<th>Direction of wind</th>
<th>Windward</th>
<th>Leeward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind angle, ( \theta )</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>( C_{pe} )</td>
<td>-0.3715</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

**Table – 2**

<table>
<thead>
<tr>
<th>Direction of wind</th>
<th>Windward</th>
<th>Leeward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind angle, ( \theta )</td>
<td>90°</td>
<td>90°</td>
</tr>
<tr>
<td>( C_{pe} )</td>
<td>-0.8</td>
<td>-0.7314</td>
</tr>
</tbody>
</table>

**D. Calculation of Wind Load (Wind Perpendicular to the Ridge):**

The wind loads are shown in figure 4.

Considering internal pressure,

Wind load at each intermediate node, \( W_3 = (-0.3715 - 0.5) \times 1.32 \times 8.385 = -9.645 \) kN

Wind load at end nodes \( W_3 = \frac{W_3}{2} = -4.823 \) kN

Wind load at each intermediate node, \( W_4 = (-0.5 - 0.5) \times 1.32 \times 8.385 = -11.068 \) kN

Wind load at end nodes \( W_4 = \frac{W_4}{2} = -5.534 \) kN

Wind load perpendicular to the ridge by considering internal pressure is Load Case 3.

Considering suction,

Wind load at each intermediate node, \( W_3 = (-0.3715 + 0.5) \times 1.32 \times 8.385 = 1.422 \) kN
Wind load at end nodes = \( W_3 \) = \( \frac{1.422}{2} \) = 0.711 kN

Wind load at each intermediate node, \( W_4 = (-0.5 + 0.5) \times 1.32 \times 8.385 = 0 \)

Wind load at end nodes = \( W_5 \) = \( \frac{0}{2} \) = 0

Wind load perpendicular to the ridge by considering suction is Load Case 4.

**Calculation of Wind Load (Wind Parallel to the Ridge):**

The wind loads are shown in figure 5.

Considering internal pressure,

Wind load at each intermediate node, \( W_5 \) = \( (-0.8 - 0.5) \times 1.32 \times 8.385 = -14.388 \) kN

Wind load at end nodes = \( W_5 \) = \( -\frac{14.388}{2} \) = -7.194 kN

Wind load at each intermediate node, \( W_6 \) = \( (-0.7314 - 0.5) \times 1.32 \times 8.385 = -13.629 \) kN

Wind load at end nodes = \( W_6 \) = \( -\frac{13.629}{2} \) = -6.815 kN

Wind load parallel to the ridge by considering suction is Load Case 5. Considering suction,

Wind load at each intermediate node, \( W_5 \) = \( (-0.8 + 0.5) \times 1.32 \times 8.385 = -3.320 \) kN

Wind load at end nodes = \( W_5 \) = \( -\frac{3.320}{2} \) = -1.660 kN

Wind load at each intermediate node, \( W_6 \) = \( (-0.7314 + 0.5) \times 1.32 \times 8.385 = -2.561 \) kN

Wind load at end nodes = \( W_6 \) = \( -\frac{2.561}{2} \) = -1.281 kN

Wind load parallel to the ridge by considering suction is Load Case 6. (-) ve wind load indicates the wind force acting away from the structural elements.

**V. LOAD COMBINATIONS**

The following load combinations are considered in the design of the roof truss:

- Load Combination 1: 1.5 (DL + LL)
- Load Combination 2: 1.2 [DL + LL + WL (Load Case 3)]
- Load Combination 3: 1.2 [DL + LL + WL (Load Case 4)]
- Load Combination 4: 1.2 [DL + LL + WL (Load Case 5)]
- Load Combination 5: 1.2 [DL + LL + WL (Load Case 6)]
- Load Combination 6: 1.5 [DL + WL (Load Case 3)]
- Load Combination 7: 1.5 [DL + WL (Load Case 4)]
- Load Combination 8: 1.5 [DL + WL (Load Case 5)]
- Load Combination 9: 1.5 [DL + WL (Load Case 6)]
- Load Combination 10: 0.9 DL + 1.5 WL (Load Case 3)
- Load Combination 11: 0.9 DL + 1.5 WL (Load Case 4)
- Load Combination 12: 0.9 DL + 1.5 WL (Load Case 5)
- Load Combination 13: 0.9 DL + 1.5 WL (Load Case 6)
- Load Combinations 14 to 25 are also considered in the design of the roof truss by taking wind in the reverse direction. They are similar to Load Combinations 2 to 13.

**VI. ANALYSIS AND DESIGN OF ROOF TRUSS**

The roof truss is analyzed and designed by STAAD.Pro V8i. Limit State Method is adopted in the design of truss members. The critical forces in the truss members and the design results are shown in Table 3 and Table 4 respectively.

<table>
<thead>
<tr>
<th>Types of member</th>
<th>Member No.</th>
<th>Maximum Tensile Force (kN)</th>
<th>Load Case</th>
<th>Member No.</th>
<th>Maximum Compressive Force (kN)</th>
<th>Load Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom Chord Member</td>
<td>1</td>
<td>90.54</td>
<td>Load Combination-1</td>
<td>1</td>
<td>95.02</td>
<td>Load Combination-1</td>
</tr>
<tr>
<td>(1 to 6)</td>
<td>10</td>
<td>112.04</td>
<td>Load Combination-1</td>
<td>7</td>
<td>101.23</td>
<td>Load Combination-1</td>
</tr>
<tr>
<td>Top Chord Member</td>
<td>15,17</td>
<td>35.72</td>
<td>Load Combination-1</td>
<td>15,17</td>
<td>54.50</td>
<td>Load Combination-12</td>
</tr>
<tr>
<td>(7 to 14)</td>
<td>21,26</td>
<td>36.09</td>
<td>Load Combination-12</td>
<td>22,27</td>
<td>20.88</td>
<td>Load Combination-12</td>
</tr>
<tr>
<td>Tie Members</td>
<td>15,17</td>
<td>35.72</td>
<td>Load Combination-1</td>
<td>15,17</td>
<td>54.50</td>
<td>Load Combination-12</td>
</tr>
<tr>
<td>(19 to 28)</td>
<td>21,26</td>
<td>36.09</td>
<td>Load Combination-12</td>
<td>22,27</td>
<td>20.88</td>
<td>Load Combination-12</td>
</tr>
</tbody>
</table>
VII. Check for Deflection

Maximum deflection in the 20 metre span roof truss due to Dead Load, Live Load and Wind Load in working condition is 1.002 mm.

Allowable deflection for the roof truss is \( \frac{L}{250} = \frac{20000}{250} \text{ mm} = 80 \text{ mm} > 1.002 \text{ mm} \).

Hence, the truss is safe.

VIII. Conclusions

All loads for the 20 metre span roof truss have been calculated by considering IS:875 (Part I, II and III). The analysis and design for the same have been carried out by STAAD.Pro V8i. Effect of stress reversal has been taken into account in the analysis of the truss.

REFERENCES

[14] STAAD.Pro V8i (SELECT series 6), Bentley Systems, Inc.