Analysis and Design of Steel Hangars with the Effect of Prestressing

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ABSTRACT
In the present paper, prestressed steel truss is modeled and analysed using STADD-Pro software. The data used for preparation of model is that of an airport building. Both non-prestressed and prestressed analysis of truss of the Hangar Building for various parameters using different span configurations is performed and comparison of various parameters has been made.
Keywords – Hangar Building, STAAD.pro.

1. INTRODUCTION
Steel is the most important construction material at the present time due to lightweightedness, the presence of high elastic modules, energy absorption capacity in seismic condition and because it provides high construction speed. Particularly steel prestressing is the controlled introduction of stresses in or whole part of the structure, which is under the action of external loading, so that stresses opposite to those originating from its own weight and the loading are produced.

The object of the paper is to perform the analysis and design for the hangar building using non-prestressed steel and prestressed steel technique. The paper also includes the comparative study of prestressed and non-prestressed steel sections in relation with material requirement and cost of the project. In many steel structures such as beams trusses, frames, etc. prestressing is done by tendons from high strength materials. Tensioning affects the pattern and the condition of service of the structures, increases its static indeterminateness and determines the way by which prestressing is done.

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2. **Methodology**

A parametric study without prestressing for analysis and design of steel truss using STADD.Pro software is carried out. The same is done with prestressing. The results are compared with the results obtained from conventional truss model.

3. **Technique**

Prestressing is the imposition of stress upon a steel structure before it is placed into service. The tendons for example are anchored by their ends into the structure and remain tensioned, working together with the structure under loading. Prestressing forces are introduced in a structural member in the reverse direction to those which originate in the member of the structure under external loading. Prestressing is applied to the structure which in service it increases the load carrying capacity of that structure it is known as post tensioning. The prestressing of steel structures is generally performed by using the tendons. Tendons are tensioned elements that are used to produce compression in the structure. Generally, high strength steel tendons are stretched between two anchorages and jacked to about three fourth of their ultimate strength. Tendons are usually connected to a main structural member at diaphragms along its length. Diaphragms assure the stability of the members during prestressing, and the tendon should have close contact with the diaphragms. However the diaphragm design should ensure free longitudinal displacement of the tendon during its tensioning.

3.1 **Problem Considered**

Analysis and design of a non prestressed steel hangar building at Airport for the data provided below

- Building Dimensions = 40 m * 50 m * 11.5 m
- Roofing Material = G. I. sheets
- Category – I
- Basic Wind Speed = 44 m/sec

![Figure 2 Hangar Building of 40m span](image)

![Figure 3 Dimensions of 40 m span truss](image)

L (AC) = 40 m

L (AB) = L (BC) = 21.078 m

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L (BM) = L (BN) = 6.316 m  
L (AD) = L (KL) = L (ST) =L (OM) = L (CT) = L (SR) =1.82 m  

3.2 Load calculations

1. The dead load comprises of dead load from the purlins and dead load of the truss itself.
   (Selecting Pratt truss)  
   Total dead load on the truss = 165.36 KN; Load per node = 7.515 KN; DL at end pts = 3.757 KN

2. Imposed load per node =10.581 KN; IL at end panel points= 5.29 KN

3. The design wind speed Vz = K1*K2*K3*Vb = 49.43 m/sec  
   Pz = 0.6 *Vz^2 = 147 Kg/m^2  
   Wall opening area is of 20%, hence Cpi = 0.7

Wall normal to ridge | Wall parallel to ridge |
---------------------|----------------------|
Windward Cpe = -0.528 | Windward Cpe = -0.716 |
Leeward Cpe = -0.4   | Leeward Cpe = -0.6   |

Wind load per node ={(Cpe + Cpi)*Pz*sloping area)/11}  
= ((1.416*147*210.78)/11)  
= 3988.57 Kg = 39.88 KN

Wind load at end points = 19.94 KN

4. To carry out the prestressing of steel truss following parameters are considered.
   Ftot = 1690.24 kN; fm= 206.82 N/mm² ; ft = 1000 N/mm²

The tendon and the member cross section areas required are worked out by using following expressions.

\[ At = \frac{(\eta_1 \psi \beta F_{tot})}{[(f_{m}(1+\eta_2 \psi))([(\eta_1-\eta_2) \psi] \cdot 1] \right) \]
\[ Am = \frac{F_{tot}}{[(f_{m}(1+\eta_2 \psi)]} - [ At / \beta ] \]

Where, n1 and n2 = overloading and underloading factors  
β = (E/ E t) = ratio of moduli of elasticity of member and the tendon  
α = Cross section of the member, reduced to the rigid material  
Ftot = total force acting on the member. ;  K = material distribution factor

And the coefficients are K=5, ψ = 0.9, β = 1,η1 = 1.1, η2 = 0.9

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The tendon cross sectional area required comes out to be 1070.96 mm² and the tendon diameter used is 38 mm. The minimum cross sectional area required is 3445.15 mm², providing sections as ISMC 350. The initial force due to prestressing is calculated as
\[ Z = \psi * f_m * A_m = 1141.504 \text{kN} \]

The various load combinations used are as follows:

Table 2: Bending moment and shear forces on the purlin

<table>
<thead>
<tr>
<th>Load Combinations</th>
<th>BM (kN.m)</th>
<th>SF(kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Parallel</td>
</tr>
<tr>
<td>DL+IL</td>
<td>1394.8</td>
<td>464</td>
</tr>
<tr>
<td>DL-WL</td>
<td>1164.8</td>
<td>234</td>
</tr>
</tbody>
</table>

3.3 Analysis Results
These loads of purlin and truss are applied then analysis is carried out. The maximum loads coming in the members of the truss are found out with their nature i.e. in tension or compression. The member carrying the maximum force is designed depending on the nature of force carried by that member.

By doing analysis of the truss, the forces in the different members of the truss with and without prestressing are found out by using STADD.Pro tools and values of the forces are tabulated below

3.3.1 Comparison of different spans of Hangar Building

Table 3: Comparison of forces for different spans

<table>
<thead>
<tr>
<th>Member</th>
<th>35m span</th>
<th>40m span</th>
<th>43m span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Axial force (KN)</td>
<td>Max(+ve) and Max(-ve)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-prestressed</td>
<td>Prestressed</td>
<td>Non-prestressed</td>
</tr>
<tr>
<td>Tie member</td>
<td>-202.43</td>
<td>-191.53</td>
<td>-226.24</td>
</tr>
<tr>
<td>Principal Rafter</td>
<td>172.52</td>
<td>159.72</td>
<td>209.04</td>
</tr>
<tr>
<td>Other members</td>
<td>-1042.54</td>
<td>-900.86</td>
<td>-1211.58</td>
</tr>
<tr>
<td>Tie member</td>
<td>466.434</td>
<td>457.00</td>
<td>537.26</td>
</tr>
<tr>
<td>Principal Rafter</td>
<td>-185.33</td>
<td>-176.88</td>
<td>-200.65</td>
</tr>
<tr>
<td>Other members</td>
<td>89.68</td>
<td>82.33</td>
<td>110.32</td>
</tr>
</tbody>
</table>
Table 4: Comparison of Sections provided for different spans

<table>
<thead>
<tr>
<th>Member</th>
<th>35m span</th>
<th>40m span</th>
<th>43m span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-prestressed</td>
<td>Prestressed</td>
<td>Non-prestressed</td>
</tr>
<tr>
<td>Tie member</td>
<td>ISMC350</td>
<td>ISMC300</td>
<td>ISMC400</td>
</tr>
<tr>
<td>Principal Rafter</td>
<td>ISMC350</td>
<td>ISMC300</td>
<td>ISMC400</td>
</tr>
<tr>
<td>Other</td>
<td>ISA 70<em>70</em>8mm</td>
<td>ISA 65<em>65</em>8mm</td>
<td>ISA 75<em>75</em>8mm</td>
</tr>
</tbody>
</table>

Table 5: Comparison of % Saving in weight for different spans

<table>
<thead>
<tr>
<th>Member</th>
<th>35m span</th>
<th>40m span</th>
<th>43m span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-prestressed</td>
<td>Prestressed</td>
<td>Non-prestressed</td>
</tr>
</tbody>
</table>

3.4 Design of column

The maximum load and maximum moment is taken from the analysis done. It comes out to be  
P = 1100 KN ; M = 120 kN-m  
Selection of section
Zxx required = M / \( \sigma_b \)
But \( \sigma_b = \) permissible bending stress
\[ \sigma_b = 0.66 \times Fy = 0.66 \times 240 = 158.4 \text{ N/mm}^2 \]
Therefore Zxx required = \( (120\times10^6) / 158.4 \) = 757.57 cm³
Selecting ISMB 400
Zxx provided = 1022.9 cm³; \( t_w = 8.9 \text{ mm} \); \( t_f = 16.0 \text{ mm} \)
Since Zxx provided is more than Zxx required ; so section is safe in bending

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Check for shear stress

\[ d_w = 400 - (2 \times t_f) = 368 \text{ mm} \]

\[ T_v \text{ calculated} = F_v / \left( d_w \times t_w \right) = \left( 80 \times 10^3 \right) / \left( 368 \times 8.9 \right) = 24.42 \text{ N/mm}^2 < 0.4 \text{ } F_y \]

Hence the selected section is safe in shear.

The designed column section is 2 X ISMB 400.

3.5 Design of column base

e = 108.33 \text{ mm}

L = 400 + (2 \times 120) = 640 \text{ mm}

\[ e/L = 109.09/640 = 1/5.8667 \]

Eccentricity lies between L/3 to L/6

\[ x = 3 \left( (L/2) - e \right) = 3 \left( (640/2) - 109.09 \right) = 632.73 \text{ mm} \]

\[ B = (2P) / \left( (x \sigma_c) \right) = (2 \times 1100 \times 10^3) / (632.73 \times 4) \approx 1000 \text{ mm} \]

Maximum compressive stress in concrete = 4*\(\frac{(869.14)}{1000}\) = 3.476 N/mm²

Stress at critical section \(x - x = \frac{3.476 \times (632.73 - 120)}{632.73} = 2.816 \text{ N/mm}^2 \)

Moment at section \(x - x = 2.816 \times 120 \times \frac{120}{2} + \frac{(3.476 - 2.816)}{2} \times \frac{(2/3) \times 120}{2} \times 120 = 23,443.808 \text{ N/mm}^2 \)

Moment of resistance = \(\frac{1}{6} \times 1 \times t^2 \times 185 \text{ N-mm} \)

Moment of resistance = Moment

Or \(1/6 \times 1 \times t^2 \times 185 = 23443.808 \)

Or \(t = \left[ \frac{(6 \times 23443.808)}{185} \right]^{1/2} = 27.24 \text{ mm} \)

\(\approx 30 \text{ mm} \)

Provide a 1000*640*30 mm moment resisting column base thick base plate.

4. CONCLUSION

By adopting prestressing in steel structures one can achieve

1. High range of elasticity on the structure
2. Prestressing also helps in reducing member stresses and deflections that are responsible for feeling of lack of safety of the structure
3. Due to the reduction of stresses, prestressing enhances the fatigue resistance of the steel structure.
4. Prestressing increases the load carrying capacity of the structure

Due to increase in the load carrying capacity of the structural one can achieve the economy in the material consumption. By doing prestressing of the steel structure about 12-17 % material can be saved. Prestressed steel hangar building has required the material

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5. REFERENCES

2. The various IS code used for the reference IS 800-1984, IS 875 – 1987, IS hand book No. 1.which are used for use of structural steel in general building construction, loading and properties of structural steel rolled sections.

AUTHOR

Amruta Jagdish Killol received the B.E. and M.tech. degrees in Civil Engineering from G.H.Raisoni College of Engineering in 2010 and ShriRamdeoibaba College of Engineering and Management in 2012, respectively. During 2011-2012, she frequently visited in different Research Laboratories. She is now continuing with the same and working as an Asst.Professor in Civil Engineering Department of GuruNanak College of Engineering and Management.