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WARREN TYPE BEAMS COMPARISON WITH DIFFERENT LAYOUT, MADE OF CHS CROSS SECTIONS

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Abstract: The aim of the present work is to find the optimized relation (less mass) between height and the number of braces at Warren type beams to cover large spans. The larger height can cause less member force and stress, but larger length leads tolarger reduction factors for overall buckling and in that case more cross section area is needed. It has a mass enlarging effect. The relations between the tubular height and mass, the height and steel grades, the height and profile forming technologies are given.
Keywords: Warren type beams, optimized relations

1. INTRODUCTION

Warren beams are a kind of truss, used to cover large spans, which would not be possible to cover with simple beams due to the deflection limit.

Under gravity loads, the efforts are like in the picture. Red sections are under compression and blue sections are under tension (Figure 1).

Elements under compression have to be calculated with reduction factor to avoid overall buckling.

The recommended geometry for this kind of structures is (Figure 2): $45° \le \alpha \le 60°$, $2h \le a \le h$

Figure 1. Budapest airport terminal building truss structure

2. THE LAYOUT

The building has been designed to be the boarding lounge of an airport located in Avila, Spain. The reason of the location is because it has one of the most adverse weather conditions (snow and wind) in Spain.

The dimensions of the building are 40x40 m with a height of 15 m. The structure consists in 5 frames with 40 m span length, with a distance of 8m between them. We have made the calculation with the following layouts:

- 50 braces, 1,6m distance between them
- 40 braces, 2m distance between them
- 32 braces, 2,5m distance between them
- 20 braces, 4m distance between them
- 16 braces, 5m distance between them

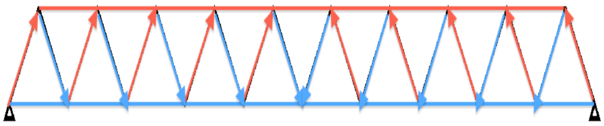

Figure 2. Layout of the Warren type beam

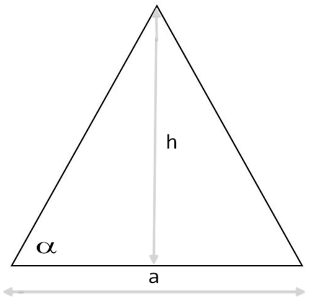

Figure 3. Triangular part of the structure with two braces and a chord

3. THE CALCULATION METHOD

The loads have been calculated following the recomendations of CTE [1] (Código Técnico de le Edificación, Technical Building Code in English) and EAE [2] (Instrucción de Acero Estructural, Instruction of Structural Steel in English), Spanish document issued by Ministry of Building.Combination of actions for ultimate limit states and persistent or transient situations:

$$\sum\nolimits_{j\geq 1}\gamma_{G,j}G_{k,j}+\gamma_{Q,1}Q_{k,1}+\sum\nolimits_{i>1}\gamma_{Q,1}\Psi_{0,i}Q_{k,j} \tag{1}$$

Considering the simultaneous action of:

- All permanent actions in design value ($\Upsilon_G . G_k$), like dead loads
- Any variable action in design value ($\Upsilon_Q . Q_k$) like wind, snow, use, etc. We choose one as predominant, and make this calculation as many times as variable actions are, each time one of them will be the predominant one, and we use the most unfavorable situation of combination
- Rest of variable actions, in combination value calculation ($\Upsilon_Q . \Psi_0 . Q_k$)

$$\Upsilon_G = 1{,}35 \text{ , } \Upsilon_Q = 1{,}5 \text{ , } \Psi_{0\,\text{snow}} = 0{,}7 \text{ , } \Psi_{0\,\text{wind}} = 0{,}5 \text{ , } \Psi_{0\,\text{flat roof}} = 0.$$

According to it, horizontal loads are the following ones depending on the number of braces

- 50 braces: 17,6213151kN/m + 10 %dead load
- 40 braces: 15,3851076 kN/m + 10 %dead load
- 32 braces: 13,5961416kN/m + 10 %dead load
- 20 braces: 10,9126926kN/m + 10 %dead load
- 16 braces: 10,0182096 kN/m + 10 %dead load

The required cross-section area has been calculated following the recommendations of CIDECT manuals through iteration [3].

$$A \geq \frac{N_{b\,Rd}\gamma_M}{\chi \bullet f_y} \tag{2}$$

where: A area of the cross section, $N_{b,Rd}$ load, f_y yield strength of steel, Υ_M safety factor (in this case 1,25, partial factor of safety on the ultimate strength of the material or section, and the resistance of the joints, according to CTE), χ reduction factor

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}}, \ \chi \leq 1,$$

with

$$\Phi = 0.5[1 + \alpha(\lambda - 0.2) + \lambda^2] \tag{3}$$

where: $\alpha = 0{,}21$ for hot-forming, $\alpha = 0{,}34$ cold-forming

The non-dimensional senderness $\bar{\lambda}$ is determined by

$$\bar{\lambda} = \frac{\lambda}{\lambda_E} \text{ with } \lambda = \frac{l_b}{i}$$ (l_b = effective buckling length, i = radius of giration)

$\lambda_E = \pi\sqrt{\frac{E}{f_y}}$ (“Eulerian” slenderness)$E = 210\ 000$ N/mm^2

We do not consider the nodal stability including punching shear, chord plastification, ect.

4. THE RESULTS

We have made the caclutation with different conditions. We have changed the profile production technology (hot rolled – cold formed), the number of braces (from 16 up to 50), the used steel grades (S235, S275, S355).

4.1. Hot-forming profile, different number of braces, steel grade is S235

With the different number of braces we have made a great amount of calculations changing the height of the truss between 2 and 8 meters to find the optimum height. Figure 4 shows the results.

It is visible on Figure 4 and Table 1 that the 16 braces tubular truss gives the smallest mass in all cases. This difference can be up to 44%. We did not consider the cost of the structure, where the larger number of nodes increases the cost of the structure, so it has an additional effect.

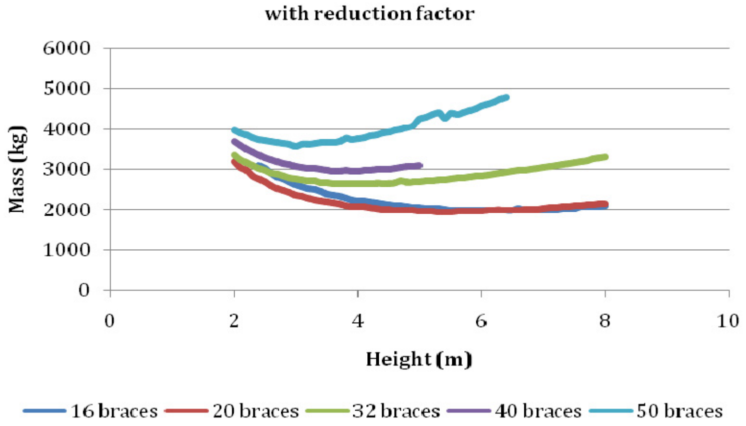

Figure 4. Mass of the structure in the function of the height with different number of braces

Table 1. Optimum height, weight of the structure with different number of bracings

	Optimum heigth (m)	Optimum weight (kg)	Relation between optimum height and distance between braces
16 braces	6,7	1990,768369	1,34
20 braces	5,4	1935,274527	1,35
32 braces	4,1	2631,169024	1,64
40 braces	3,7	2952,463064	1,85
50 braces	3	3571,14314	1,875

4.2. Hot-forming profiles,the same number of braces and different steel grades

In this case we have considered hot-forming profiles,the same number of braces (32) and different steel grades.It is visible on Figure 5 and Table 2 that the S355 steel gives the minimum mass structure in all cases. This difference can be up to 39%. We did not considered the price of the steel. For a steel S355 the material price can be 10-15% larger that of for steel S235. The actual steel prices give the designer the information to choose the higher strength steel, or not.

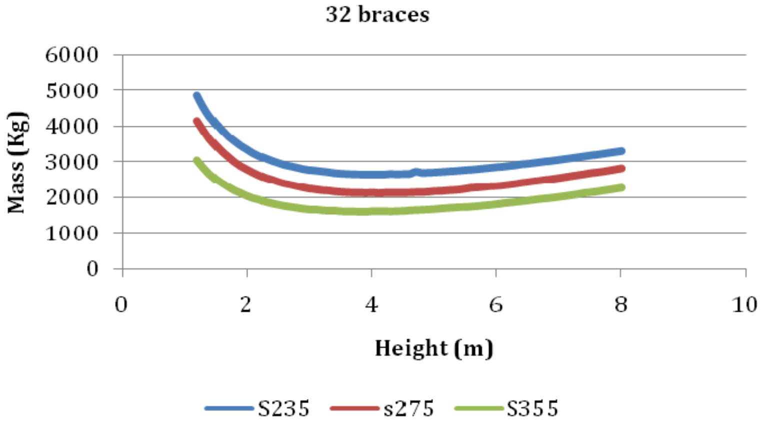

Figure 5. Mass of the structure in the function of the height with different steel grades

Table 2. Optimum height, weight of the structure with different steel grades

	Optimum heigth (m)	Optimum weight (kg)	Relation between optimum height and distance between braces
S235	4,1	2631,169024	1,64
S275	4,1	2135,097149	1,64
2355	3,9	1614,64229	1,56

4.3. Same number of braces, same steel, different forming

In this case the same number of braces used, the same steel is applied and different forming of profiles is considered. It is visible on Figure 6 and Table 3 that using the same S235 steel, the same number of braces (16)there are differences using the hot and coldformed profiles. Cold forming steel results a smaller mass, than hot rolled, but the difference is less then 10%.

Table 3. Optimum height, weight of the structure with different forming technologies (hot, cold)

	Optimum heigth (m)	Optimum weight (kg)	Relation between optimum height and distance between braces
Cold-forming	4,2	2481,793704	1,68
Hot-forming	4,1	2631,169024	1,64

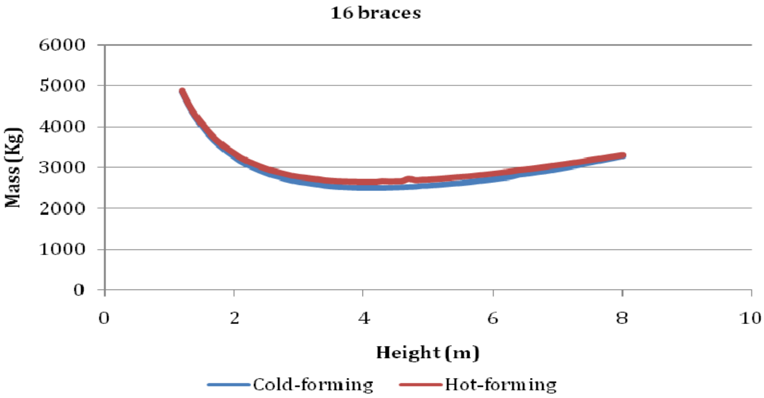

Figure 6. Mass of the structure in the function of the height with different forming technologies (hot, cold)

5. CONCLUSION

It can be observed that all the curves have more or less the same shape. If the height is very small, the mass is higher because it is needed more reaction from the elements to stand the moments due to loads.If the height is very large, the mass goes larger too because of stability phenomena.So we have to focus in the middle of the curve and the behaviour of the structure in this part.The reduction factor is not only needed to avoid overall buckling, but alsoto consider in the calculationthe kind of manufacturing of the steel (cold or hot forming), and it also depends on the yield strength.

The different variants and the conclusions are the followings:

- Hot-forming, same steel (S235), different number of braces. The more number of braces, more elements, so more mass needed.This difference can be up to 44% between 16 and 50 braces. If we consider the production cost, the difference is even larger, because the formation of nodes takes time and energy.
- Hot-forming, same number of braces (32), different steel. The higher the yield strength, means less mass, because less area will be needed. The S355 steel gives the minimum mass structure in all cases. This difference can be up to 39%.
- Same number of braces (16), same steel (S235), different forming
- The difference between hot and cold forming is small, less that 10%. The cold forming profile is better.

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