Simulative Model and Multicriteria Optimization of Truss Beam in Super-Large Columns at High Temperature

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Abstract: With the increasingly enlarged process scale and the consequent requirement for large equipment, such as column, trusses ever widely applied in civil and building engineering have been introduced in petroleum chemical industry these years. Under this circumstance, truss structure optimization emerges as a study focus to balance safety, durability and economy. In this paper, an optimization example is introduced of a main truss beam system, namely centre, and its side beams in super-large column at high temperature. The main truss beam is optimized on three counts, that is, cross-section shape of the chord members, structure height and the pairs of the web members, while side beams are optimized by compromising among workability, stress, stiffness and weight.

1 INTRODUCTION

With the rapid development of global petrochemical industry, super-large column application becomes an inevitable trend of choices in unites of this area, so how to improve the performance (mass-transfer efficiency, stability, operation safety, etc.) of the super-large column is becoming a hot topic (Wang, 2011).

Supporting beams as one of the important parts in super-large column have great impacts on mass-transfer efficiency and operation safety. Trusses ever widely applied in civil and building engineering are now tend to be used as supporting beam instead of traditional beams, such as I beams and channel beams, in super-large column. Moreover, optimum truss beam systems are believed to have following properties (Pascal, 2011): (1) enough strength to support separation or reaction apparatus, such as packings and trays, and possible less deformation to reduce structural deflection which will cause uneven or unsteady liquid flow within these apparatuses; (2) optimal shapes to lessen vortexes which aggravate the harmful gas phase turbulent move; (3) lower pressure drop; (4) material-saving, and workability; That is, to further increase the operation efficiency in large-scale chemical production, a comprehensive optimization will be inevitable. So how to optimize truss beam structure applied in petrochemical industry is an indispensable work that should be taken into account.

Many investigations about optimization of truss beams based on mathematics or FEA has been done to provide the most efficient design of a given structure that complies with all applicable strength, stiffness and light weight requirements (William and Yong, 2004). But most works aim to optimize the structure size or to adjust the relations between the design variables and state variables to reduce the cost in ambient temperature on the basis of ensuring the enough strength and less deformation.

In this case, the truss operates in super-large column, with a smaller elastic modulus of the material at field high temperature, which results in larger deformation and puts forward higher demands to optimization methods. So three criteria of simulative optimization by ANSYS have been provided to work out the least weight of the truss beams in the following work, that is, the cross-section shape combinations of chord members and web members (Kočvara, 2002), height and the pairs of the web members, which finally lessen the weight with better stiffness. Besides, factories normally tend to apply too safe truss beams as side beams. However, side beams simplified and simulated in this paper demonstrates that available I beams perform well to meet the current field applications.

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2 MODEL AND OPTIMIZATION

2.1 Structure Description

Truss beam in a vacuum column with diameter of 13700mm is called centre beam, and the side beams are in the both sides of the centre beam with a distance of 3300mm. The visual position is showed as figure 1.

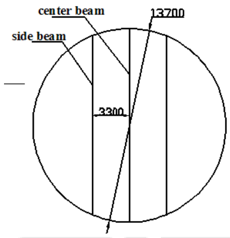

Figure 1: Distribution of beams.

The truss beam is made up of three parts, namely top and bottom chord members as well as web members (figure 2). The top chord member is fixed on the inner surface of the column by supporting brackets at both ends of the beam. This truss uses double-web member. At both sides of the structure, web members are weld to the top and bottom of chord members, by attaching on the joints board. This structure can improve the integral stability and stiffness. The initial top and bottom chords consist of two angle steels that are attached by welding.

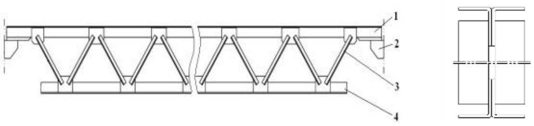

Figure 2 structure of the truss.

1-top chord member; 2-stopporting bracket; 3-ten pairs of web members; 4-bottom chord members

The truss is operated under 400℃ in the strong corrosive environment. The material selected for it in this condition is 316L with the prosperities of strong heat-resistant and corrosion-resistant. Its mechanical property parameters and initial sizes under operating conditions are collected in the table 1 (Wang, 2008).

2.2 Finite Element Simulative Model

The universal finite element software ANSYS has a rich unit library with a powerful function of before and after processing. According to the prosperities of each unit, the structure of the truss and the load on it, when calculated, are simplified as follows:

(1) Unites attributes. Truss is a kind of plane structure, which is mainly bending deformation when being loaded. So when modeled, chord members can be built with the attribute of beam 188, which is an more appropriate unit in this linear and large angle rotation or nonlinear big strain project, as well as web members.

Table 1: Initial parameters.

parameter	value	remarks
dist/mm	670	nodal distance
height/mm	700	height between top and bottom nodes
h/mm	900	initial whole height of truss beam
l_g/mm	13440	length of truss
q_{top}/N/mm^2	20.698	top linear load
q_{bottom}/N/mm^2	1.612	bottom linear load
E/N/mm^2	1.69e5	elastic modulus
ε	0.31	Poisson's ratio
den/Kg/mm^3	7.85e-6	density
n	10	Initial pairs of the web members
bottomw1/mm	450	width of chord members
bottomw2/mm	200	height of chord members
bottomt1/mm	30	leg thickness of chord members
bottomt2/mm	60	waist thickness of chord members
topw12/mm	164	width of web members
topw22/mm	82	height of web member
topt12/mm	20	leg thickness of members
topt22/mm	40	waist thickness of members
G_p /N	924095	the weight of the packing and the top chord member
G_{dis} /N	71988	the weight of the distribution and the bottom chord member
[σ] /Mpa	90.9	allowable stress
sigi	10	allowance displacement

(2) Cross-section showed as figure 2. Initially chord members and web members are given a cross section of T steel formed with two welded angle beams.

(3) Pressure on truss. Pressure on axis is called the linear load. So it is necessary to convert the load on the top and bottom chord members into linear load q before calculation (Xu et al., 2003).

$$q_{top} = \frac{G_p}{S_{col}} \times \frac{S_g}{l_g} \quad (1)$$

$$q_{bottom} = \frac{G_{dis}}{S_{col}} \times \frac{S_g}{l_g} \quad (2)$$

where S_{col} is the area of the column, S_g is the equivalent area of the truss beam (see the figure4). Based on (1), (2) and table 1, the value of q_{top} is 20.698N/mm and q_{bottom} is 1.612N/mm

(4) Constraints on truss. According to trusses installation and the field operation, the top chord member is imposed surface constraint that the Y and Z coordination directions are fixed. It could only stretch freely in X direction, while the bottom chord member is confined to rotate in Y-Z plane.

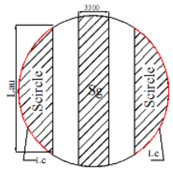

Figure 3: Equivalent loaded area of beams.

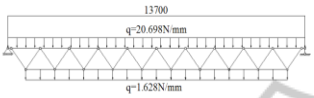

Figure 4: Simulative model.

2.3 Calculation and Result Analysis

Based on the above parameters and former constraints, simulative model can be built by ANSYS and the results will be gained after being defined as a static analysis.

When long thin rod bears uniform load, the distorting stress is far less than the bending stress, only the bending stress needs to be checked. The main evaluated results for chord members are the bending stress and the deflection. Meanwhile, Von-Mise stress is regarded as the failure criteria for material of 316L failing in the plastic state. The following are the Von-Mise stress and deflection figures of the truss beam

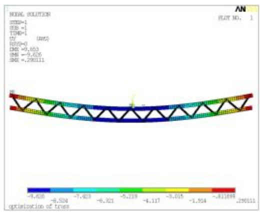

Figure 5: The von miss stress nephogram of truss.

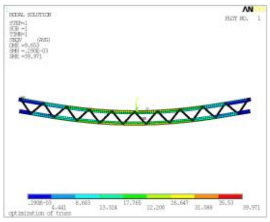

Figure 6: The deflection of the truss.

Shown in the above two figures, the maximum stress $\sigma_{\max} = 39.97$ is much less than the allowable stress, while the maximum deflection $sigi_{\max} = 9.64$ approaches the extreme displacement, which guides the structure to be optimized by improving the stiffness of the truss. Too safe strength and a little strict deformation requirement, the design of truss is judged to be a little conservative.

3 STRUCTURE OPTIMIZATION

3.1 Variables and Optimum Method

The optimization problem is formulated and solved simultaneously in design and state variables, where the state variables include both nodal displacements and element forces. So it is necessary to declare the variables first.

In this paper, the design variables are height, topw1, topw2, topt1, topt2, topw11, topw12, topt11 and topt12. And the state variable is sigi. Stress as the state variable can't be defined in ANSYS. It is checked by Von-Mise stress when the iteration is finished. Volume represented by vtot is regarded as the objective function to gain the least weight.

To ensure the iteration converge as fast and accurate as possible, First-Order solution is the proper method, whose iteration time is defined 60.

3.2 Optimization Criteria

3.2.1 Cross Section Shape Optimization of Chord Member

Firstly the initial variables are optimized based on optimum model 3.1 on the condition of $h = 900$, $h = 800$, $h = 700$ by ANSYS. Secondly the initial cross section of chord members is replaced by two channel steels with I steel attribute(ITI) welded with each other based on the former optimization; thirdly the bottom chord is replaced with two angle steels of T steel attribute(ITT)welded with each other based on the former two optimization. Comparisons of the above three types of the cross section are showed in the figure 9.

It is obvious that truss beam is more applicable than I beam in super larger column, and from figure 9, I steel cross section for chord members is the best choice among the three cross sections. Besides, the volume of truss with I steel cross section under three given heights is less than that with T cross section, which indicates truss stiffness per volume with I steel cross section is larger than that of T cross section. So ITI is the best cross section combination for the truss, and is applied in the optimization of the pairs of web members

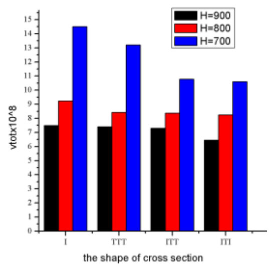

Figure 7: Volume comparisons of different cross section types.

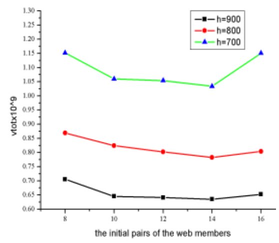

Figure 8: Comparisons of volumes with ITI cross section under different pairs of web members.

3.2.2 Optimization of the Pairs of Web Members

Simulative model will be rebuilt when the pairs of web members are redefined. The pairs of the web members n are ranged from 8 to 16 with the increments of 2. Then optimization proceeds similarly to 3.2.1. Based on the outputting results, vtot venues to n is mapped in the figure 10

As shown, under the same pairs of web members, the higher the height is, the larger the truss volume will be. That means there must be a compromise between height and volume. And $n=14$ are the best pairs of web members for $h=900$, $h=800$, $h=700$. Considering there is not so much gap of volume from $n=10$ to $n=14$ when $h=900$, it is more financial to produce ten pairs of web members.

Finally, the best two optimum results with ITI cross section are picked out to contrast with initial result with TTT cross section as follows:

(1)When height is more important than volume

$$h\% = \frac{800-900}{900} = -11.11\% \tag{3}$$

$$vtot\% = \frac{7.83-7.41}{7.41} = 5.67\% \tag{4}$$

The best result is $n=14$, $h=800$ with ITI cross section, which lowers the height by 11.11%, but only increases the volume by 5.67%.

(2)When volume is more emphasized:

$$vtot\% = \frac{6.45-7.41}{7.41} = -12.96\% \tag{5}$$

The optimum result is $h=900$, $n=10$ with ITI cross section, which can reduce the weight by 12.96% and decrease the cost by choosing $n=10$ instead of $n=14$.

3.2.3 Side Beam Optimization

The simulative model and constraints of the side beam are the same as that of the centre, while relevant sizes are replaced by the size given in 2.1. The linear load is gained from the following function:

$$q_{au} = \frac{2G_{total}S_{circle}}{S_{total}(2L_c + 2L_{au})} \tag{6}$$

In equation (6) (Xu et al., 2003), G_{total} is the total weights of the packing and distributor which are loaded on S_{total}. S_{circle} and L_{circle} showed in figure 4 is respectively the area and the length of the circle cut by the two side beams.

From the viewpoint of engineering, it is preferable for stability to regulate the centre deformation equal to that of side beam. In this part, truss beam with I steel cross section as side beam is compared with I beam under the same beam height.

Table 2: The optimum results of side beam.

type	*height*/mm	*vtot*/mm^3
truss beam	h=800(n=12)	1.38E+08
I-beam	h=800	1.49E+08

From the table 2, the volume of truss beam is near to that of I beam. It can be concluded that I beam is more appropriate to side beam not only for stability but also for lower manufacturing cost.

4 CONCLUSIONS

Multicriteria optimization of truss beam applied in super-large column at 400℃ is presented in this study. It demonstrates that chord members with I steel cross section are superior to that traditional with T steel cross section, not only in material-saving, but also in uniformity of liquid distribution. Influence of pairs of web members on optimization reflects how big the angle between chord member and web member is more favourable. As for side beam, judging from the stability and lower cost, it is best to choose I beam rather than truss beam on the foundation of enough strength and stiffness.

By contrasted the influence of different shapes on truss performance, some other shapes of truss beam cross section which may be more effective in material-saving and energy-saving can be investigated in the future. In addition, the relation of the angle between chord member and web member and the distance between web members can be tried to build in order to reduce variables, which can somewhat improve the speed of optimization.

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