APPLICATION OF PRE-STRESSING TECHNIQUES TO LARGE SPAN GIRDERS CONSISTING OF STEEL TUBES

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For large-span girders using full-length circular tubes as lower chord, the effect of pre-stressing technology on the improvement of deformation, stiffness and bearing capacity of the girders was investigated in this paper. The specific configuration is that using pre-stressed steel strands passing through the inner part of the full-length steel tube and anchored at the ends of the steel tube, and applying proper initial pre-stress force. Through theoretical analysis, the effects of pre-stressing on the vertical stiffness, bearing capacity, axial stiffness, bearing capacity and deformation control of large-span girders are studied. The results show that the magnitude of pre-stressing has no effect on the axial stiffness and equivalent vertical stiffness of large-span girders. On the other hand, the pre-stressing technology can improve the axial tension bearing capacity of long-span beams and circular tubes, however reduce the axial compression bearing capacity of circular tubes correspondingly. The vertical bearing capacity can be increased by setting reasonable pre-stressed force in the lower chord tube. By establishing a reasonable optimization process, the material can be maximized utilized and the comprehensive cost can be minimized. The pre-stressing technology can be used in large-span girders with circle tubes in buildings and bridges with bright future.

Keywords: Pre-stressing strands, Steel tube, Large-span girder, Deformation capacity, Bearing capacity, Structural stiffness

1 Introduction

With the development of construction techniques and the requirements of complex projects, large span structures increased rapidly in the past few years and may also in the foreseeable future (Tian, Hao, and Wang, 2009). In many projects, steel tubes are welded together combining the large span trusses in the design of structures with large span girders, such as bridges and large gymnasiums (Tan 2015, Z., 2013), as shown in Figure 1. With the span length increasing, the girder's deformation is difficult to control caused by the large self-weight of the girder itself, which is a serious problem faced by structural engineers.

Prestress techniques are widely used in the real project to control the deformation, provide self-centering capacity and decrease the section dimensions for structural components (Luo 2010, G. D. 2012). Cable-stayed bridges, suspension bridges, cable domes all benefits from prestress techniques providing large span and high stiffness (Chunlei, 2012).

Utilizing the prestress techniques in the large span girders lower chord made up of steel tubes is a main target of this research. The influence of the prestress techniques to the stiffness and bearing capacity of the girders both in axial and vertical are evaluated by numerical analysis.

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The optimized design procedure considering the initial prestress force to get most economical design result is also proposed.

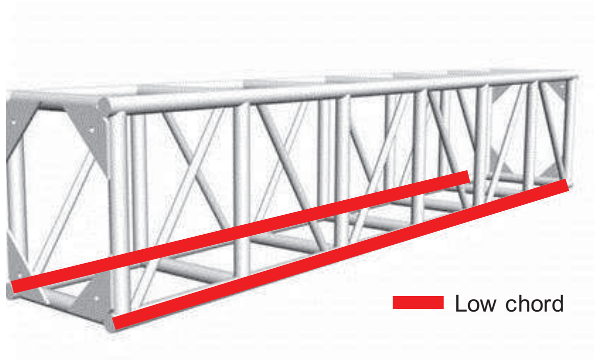

Figure 1. Low chord in steel truss girder

2 The Axial Stiffness and Bearing Capacity Influence

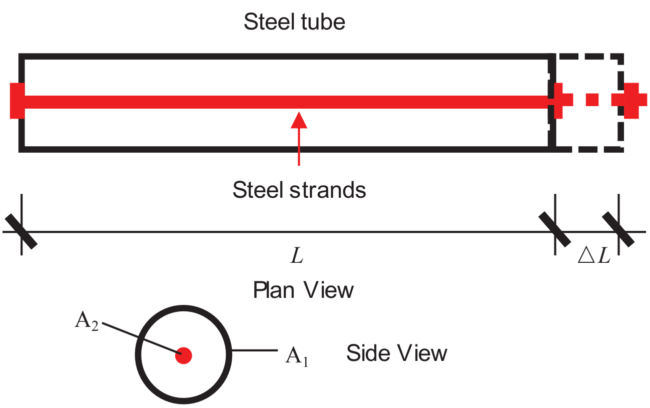

Figure 2. Axial deformation diagram

2.1 Axial stiffness

When the tube with steel strands inside bears tension or compression force F as shown in Figure 2, the both deformation of the tube and steel strands is $\triangle L$, the strain of the tube and steel strands can be calculated by Eq. (1). The axial stiffness can be derived by Eq. (2). E_1 and A_1 are the elastic modulus and section area of the steel tube. E_2 and A_2 are the elastic modulus and section area of steel strands. Eq. (2) shows that the axial stiffness of the tube with strands is only influenced by the elastic modulus and length of the components. The steel strands can increase the stiffness of the structure, however, the initial prestress force doesn't affect the axial stiffness.

$$\varepsilon = \frac{\Delta L}{L} \tag{1}$$

$$k = \frac{F}{\Delta L} = \frac{\varepsilon(E_1A_1 + E_2A_2)}{\Delta L} = \frac{E_1A_1 + E_2A_2}{L} \tag{2}$$

2.2 Axial bearing capacity

Assume that the tension yield force of steel tube is F_{ty1}, and the tension yield force of steel strands is F_{ty2}, and the steel strands won't yield before the tube yields. The compression yield or buckling strength of steel tube is F_{cy}, and the compression strength of steel strands is zero. The initial prestressed force is F_{in}. So that F_{in} should be smaller than F_{cy} to prevent compression damage. The axial bearing capacity difference of the components with or without initial prestress force is shown in Figure 3. X is the deformation of the steel tube. The abscissa of point C is shown in Eq. (3).The ordinates of point A is shown in Eq. (4). The abscissa of point B is where the tube comes to tension yield. Then the ordinates of point B can be derived by Eq. (5).

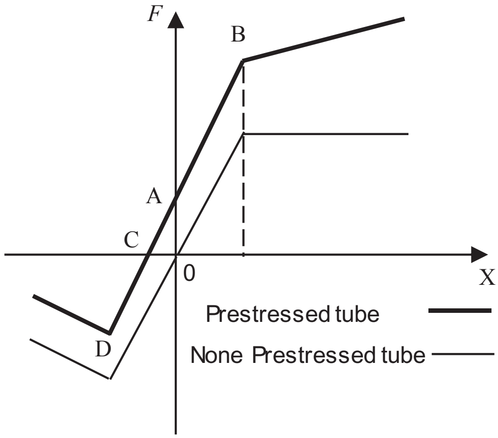

Figure 3. Axial bearing capacity of tubes with or without initial prestress force

$$X_C = -\frac{F_{in}L}{A_1E_1} \tag{3}$$

$$F_A = F_{in} \bullet \frac{E_1A_1 + E_2A_2}{E_1A_1} \tag{4}$$

$$F_B = F_{in} \bullet \frac{E_1A_1 + E_2A_2}{E_1A_1} + \frac{E_1A_1 + E_2A_2}{L} \bullet \frac{F_{ty1}}{E_1A_1} L = \frac{(F_{in} + F_{ty1})(E_1A_1 + E_2A_2)}{E_1A_1} \tag{5}$$

$$F_D = F_{in} - F_{cy} \tag{6}$$

Take B as the ultimate bearing capacity of the combination of tube and steel strands, the Eq. (5) shows that the tension bearing capacity is increased by the initial prestress force, however the compression bearing capacity of the composite structure is deceased by the initial prestress force as shown in Eq. (6).

3 The Vertical Stiffness and Bearing Capacity Influence

3.1 Vertical stiffness

Assume that two tubes are connected by a stiffness link forming a long girder, which is a simple model simulating the truss as shown in Figure 4. The low chord installs steel strands. The girder is simply supported beam, and the middle deflection is Δ. The vertical stiffness is considered the concentrated force at the middle span of the beam, which is shown in Eq. (7).

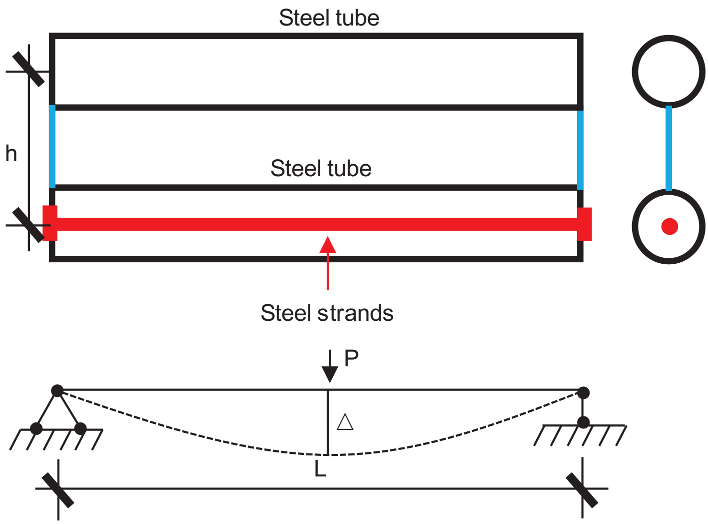

Figure 4. Vertical deformation diagram

$$k_v = \frac{P}{\Delta} = \frac{48EI}{L^3} \tag{7}$$

E and I are the equivalent elastic modulus and moment of inertia of the composite section correspondingly. The Eq. (7) shows that the vertical stiffness of the composite structures can also be increased after install the steel strands, but it is not influenced by initial prestress force.

3.2 Vertical bearing capacity

Assuming that the vertical bearing capacity is got when the lower chord tube's full section reaches to its tension yield strength at the same time, and the upper chord remains elastic, then the bearing capacity can be calculated by Eq. (8)

$$P = \frac{4F_B h}{L} \tag{8}$$

h is the distance between the upper and lower chord. So that with the initial prestress force, the vertical bearing capacity of the truss beam can be increased.

4 Optimized design procedure

For real project, the dimensions of tubes and steel strands can't be chosen any value as designer wants. How to utilize the prestressing technique, what is the best initial prestress force value and how to remain economic design result for the project is the problem to consider in this section. Assume that the tension force of the lower chord is F, the design strategy can be expressed as Eq. (9).

$$F_B = \frac{(F_{in} + F_{ty1})(E_1 A_1 + E_2 A_2)}{E_1 A_1} \geq F \tag{9}$$

F_{in} is the initial prestress force, which can be determined by Equation. (10).

$$F_{in} = 0.3 f_{ty2} \bullet A_2 \tag{10}$$

f_{ty2} is the fracture strength of the steel strands. Substitute Eq. (10) into Eq. (9) and results Eq. (11).

$$F_B = \frac{(0.3 f_{ty2} \bullet A_2 + F_{ty1})(E_1 A_1 + E_2 A_2)}{E_1 A_1} \geq F \tag{11}$$

In Eq. (11), there are only two variable, A_1 and A_2, so that an optimized design procedure is proposed to get the minimize section area of steel tubes and the minimize number of steel strands, as shown in Figure 5, Firstly, based on the conventional design result of the girder, a relative small diameter of steel tube is chosen at the beginning and the axial force of the lower girder can also got by analysis result. Substitute A_1 and F into Eq. (11) and choose the equal state. From calculation of Eq. (11), A2 is got. Then the section dimensions should be checked to make sure that it can resist the compression force caused by the steel strands without yielding and buckling, and to make sure that the steel strands can be installed into and anchored on the tube successfully. If the section dimensions meet the requirements foresaid, then A_1 can be chosen to a smaller one, until reaching the minimum of A_1. After getting the minimum section area of the tube, the updated model of the structure will be checked to make sure it can meet the requirements of the standards by time history analysis. If not, the section area of tubes should be increased until it can keep safety under the considered earthquakes. After that, the total section area of steel strands A_2, which also means the number of the steel strands can be reduced, and the initial prestress force can increase. And the modification should also be checked by time history analysis to make sure the structure safety. If not, the number of the steel strands should be increased. If yes, the design procedure comes to the end. And we got the minimum total section area both in the tube and the steel strands and keep the structure safety at the same time. Then the design result will be the most economic one.

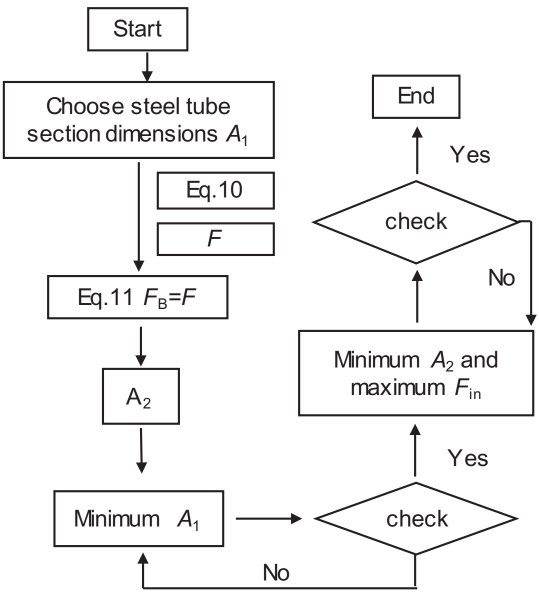

Figure 5. Optimized design procedure

5 Conclusions

In this study, the composites behavior of steel strands and tube in the application of lower chord of large span tube-truss girder are investigated. From the analysis above, some conclusions can be summarized as follows:

(i) The steel strands can increase the stiffness of the lower chord both in axial and vertical, however the initial prestress force doesn't affect the stiffness.

(ii) The initial prestress can increase the tension bearing capacity of the tube. Using this steel strands-tube composites in the lower chord of the girder can increase the vertical bearing capacity of the structure.

(iii) For the overall material used is decreased, the self-weight of the structure is also decreased. So that the application of pre-stressing technology can also reduce the structural base reaction and seismic response due to the reduction of steel consumption.

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(v) Further study should be conducted on the construction measures and detailed configurations on this kind of structure.

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