Tie bar design for a large span concrete-filled steel tubular arch bridge

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ABSTRACT: Based on a 280m span concrete-filled steel tubular arch bridge with rigid frame tie bar, located in Dongguan City, Guangdong Province, China, the tie bar design is described. There are two main characters: adopting the modern external prestress technology and applying new anti-corrosion and replacing maintenance technology. These can be widely applied in similar bridge and building engineering.

KEYWORDS: Large span concrete-filled steel tubular arch; Arch bridge; Tie bar arch; Bridge design

1. INTRODUCTION

Dongguan Waterway Bridge, located in Dongguan city, China, is a large bridge over-crossing Dongguan Waterway on the 5th expressway in Dongguan City of Guangdong Province in China. The span layout is 50 + 280 + 50m with continuous anchored and half-through concrete-filled steel tubular arch bridge attached by tie bars. Each bridge width is 26.1m, included two completely independent directions. The design loads are vehicle-over 20, trailer-120, and 3.5kN/m^2 for pedestrian. The general layout is demonstrated in Figure 1 below.

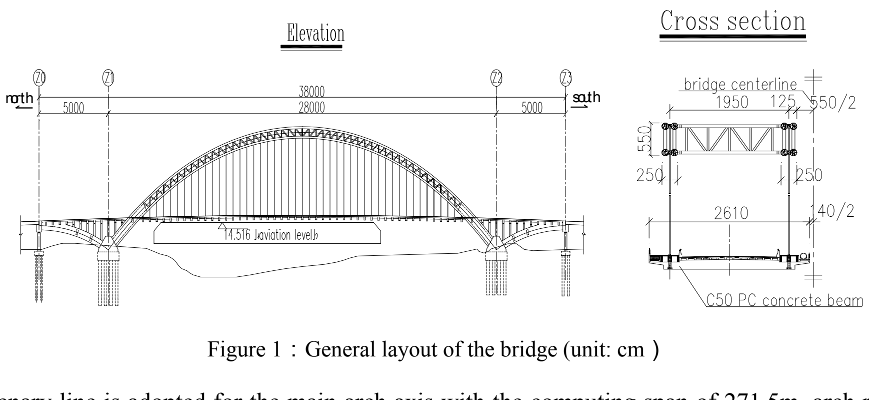

Figure 1：General layout of the bridge (unit: cm）

Catenary line is adopted for the main arch axis with the computing span of 271.5m, arch rib height of 54.3m, the ratio f/L of 1/5, and the arch axis coefficient of 1.5. The solid concrete arch rib is adopted for the side arch with the catenary arch axis of m=1.9 and the calculated f/L of 1/9.819. The equivalent cross-section is used for the main arch rib with height of 5.5m formed by 4 steel tubes of the external diameter of 1m.These are filled with concrete of Grade C50. The distance between two parallel rib is 19.5m. For improving the stability of the main rib, 12 K-shaped and 1 I-shaped wind-resistance bracings are set up between two parallel arch rings. The deck system is made of steel concrete beam grid. The prestressed rebar concrete Π - shaped slab is adopted for the deck connected together with transverse beam, longitude beam, hanger, column and the arch ribs.

2. MAIN CHARACTERS FOR THE TIE BAR DESIGN

2.1 General design

16 bunches of strand of 31Φ_j15.24 are adopted for each arch rib. Its standard strength is $R_y^b = 1860MPa$. The latest external anti-corrosion strand technology is applied with epoxy PC strand, packed with double layer PE. The detailed is shown in Figure 2.

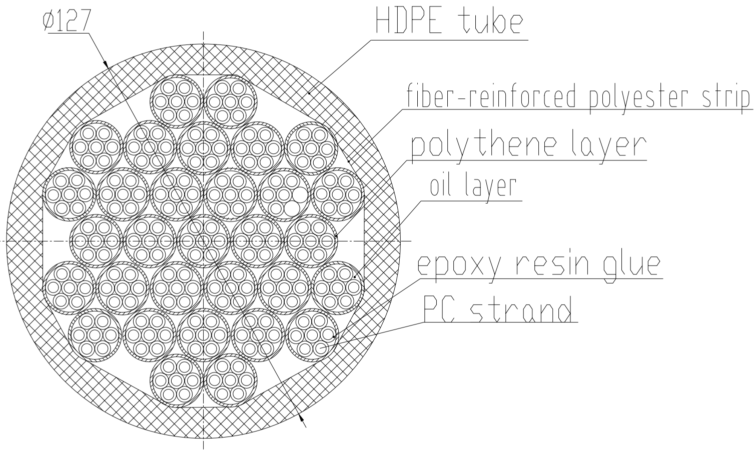

Figure 2: The tie bar cross-sectional diagram

In this bridge design, steel bunches are set on both sides and the center of arch rib. Two ends anchored on the end transverse beams of side arch. A changeable anchor is adopted for the tie bar. As for the support system of tie bar, a reliable, flexible, easy-assemble leading frame is applied. It is pre-embedded on each transverse beam.

2.2 Tension force control and stress application

The control force under anchor for each tie bar is 382.9 ton. The error must be controlled in the range of ±1.5% for each control tension force and ±1.0% for the sum of the tension force. Except for only two bunches being tensioned in two stages, the others are tensioned to end in one stage.

In the worst load case, or, in the case of dead load + vehicle + pedestrian + temperature decreasing of 25°C, the maximum applying stress isσ = 0.47R_yb = 882.6Mpa with minimum safety coefficient of 2.1. On the other hand, the tie bar stress is σ_{max} = 838.1~852.8MPa. The maximum stress amplitude is 14.7Mpa in the case of dead load + vehicle + pedestrian, while in the case of dead load, tie bar stress is σ_{max} = 838.1MPa.

Suggested by the authors, the maximum applying stress should be within 0.40~0.6R_yb for a large span tie bar arch bridge. For safety, the maximum applying stress in this bridge is set to be σ =0.47R_yb.

2.3 Prestress loss calculation for the tie bar

For best controlling the tie bar stress in the case of dead load, the relevant prestress loss must be accurately calculated. It can be calculated as shown in Figure 3.

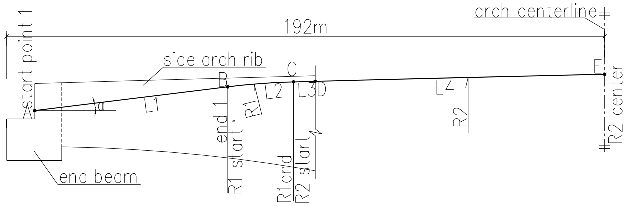

Figure 3: The computing diagram for the prestress loss of the tie bar strand

In accordance with the similar model test, the relevant friction coefficient μ_1 is 0.285, and K_1=0.00008 for the location difference coefficient for the side arch rib. For those over leading wheel, the friction can be simplified as K_2=0.0001, μ_2=0. The strand shrinkage value is set to be ΔL = 4.5mm , therefore, prestress loss can be calculated as follows.

Assuming that σ = tension stress under the anchor of the tie bar, E_y = the elastic modulus of the tie bar , E_c = the elastic modulus of the side arch rib , N = the sum tensile force under the anchor of the tie bar , A = the cross-sectional area of the side arch rib , L_c = the axis length of the side arch rib, the following formula can be derived:

1) Loss σ_1 : from end transverse beam to tie bar outlet
   If $A_1=\mu\theta+kx=\mu_1(R_1/L_2+R_2/L_3)+K_1(L_1+L_2+L_3)$
   Then $\sigma_1=\sigma\times(1\text{-e-}A_1)$
2) Loss σ_2 : from the tie bar outlet to the center of the arch
   If $A_2=\mu\theta+kx=K_2\times L_4$
   Then $\sigma_2=(\sigma-\sigma_1)\times(1\text{-e-}A_2)$
3) Loss σ_3 for anchor deformation
   $\sigma_3=E_y\times\Delta L/(L_1+L_2+L_3+L_4)$
4) Loss σ_4 for compression deformation of the side arch rib
   $\sigma_4=E_y\times N\times L_c/A/E_c/(L_1+L_2+L_3+L_4)$
5) General prestress loss $\Sigma\sigma=\sigma_1+\sigma_2+\sigma_3+\sigma_4$

Especially for strands N1 in this bridge design, the relevant data are followed:

L_1=14.934m, L_2=3.479m, L_3=2.023m, L_4=169.62m, R_1=50m, R_2=6500.1m, $E_y=1.9\times10^5$Mpa, $E_c=3.3\times10^4$Mpa , A=10m^2, L_c=45.978m, σ = 882.3Mpa, N=6126.4t

Then, the general prestress loss can be calculated as follows:

$$\Sigma\sigma=\sigma_1+\sigma_2+\sigma_3+\sigma_4=18.8+14.5+4.5+8.5$$
$$=46.3\text{MPa}$$

For the other strands, the similar calculation can be carried out without any other special difficulties.

2.4 Calculation of the tensile extension value and the membering length

2.4.1 The tensile extension value of the tie bar

It can be calculated as follows:

1) Δ_1: extension from end transverse beam to the tie bar outlet

$\Delta_1 = \sigma \times (L_1+L_2+L_3) \times [1-e^{-(\mu\theta+kx)}]/(\mu\theta+kx)/E_y$

2)Δ_2 : extension from the tie bar outlet to the center of the main arch

$\Delta_2 = (\sigma - \sigma_1) \times L_4 \times [1-e^{-(\mu\theta+kx)}]/(\mu\theta+kx)/E_y$

Especially for strands N_1 in this bridge design, the sum of extension value is followed:

$\Sigma\Delta = \Delta_1 + \Delta_2 = 0.094+0.764=0.858m$

2.4.2 Membering length for the tie bar

Without any doubt, accurate calculation of the tie bar membering length is of great importance. Assuming that the strand computing length, L, the general tensile extension value, Δ , the shortest distance from the end of PE to the anchor, the membering length of the tie bar L_2 can be derived as follows:

$L_2 = L - 2\times\Delta - 2\times L_1$

Especially for strands N_1 in this bridge design,

$L=380.111m, L_1=0.76m, \Delta=0.858m,$

Then, the membering length of the tie bar N_1 is :

$L_2=376.875m$

2.5 The change and anti-corrosion of the tie bar

In consideration of the possibility of the future change of the tie bar, a certain design improvement is adopted. For the future strand change, the strands outlet 30~50cm long from the anchor. While alternating strands, relieving the strand unit one by one by using lift jack can be adopted. As for the anti-corrosion technology, the latest within the country is adopted for the tie bar design, especially the epoxy double layer PE strand technology.

2.6 Bearing system formation for the tie bar

For decreasing the friction between the tie bar and the supporting branch, the leading wheel bearing system, or, the leading wheel frame, is designed in the bridge. The frame is welded by using steel plates, and supported by four rows of rolling wheel in consisting of the mechanical set and the stainless leading wheels. There are 16 bunches of tie bar at each end of the main arch rib. The main formation diagram can be shown in Fig. 4.

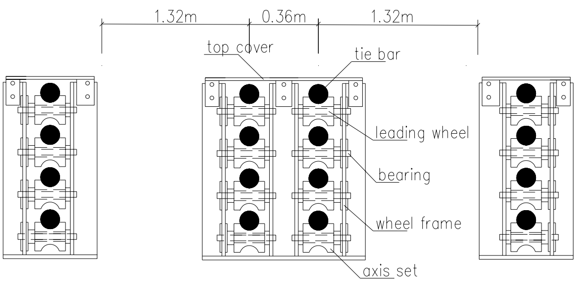

Figure 4: Diagram for a leading wheel frame

3. CONCLUSION

As for the great span of arch bridge with the tie bar, the tie bar design is of great importance. The service life of the bridge depends much on it. For applying prestress strand tie bar rationally and scientifically, the stress value range for the tie bar should be studied more deeply and carefully. On the other hand, the strand exchanging technology, during the service stage, must be improved and appended by means of those practical engineering examples.

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