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DYNAMICAL INVESTIGATION OF THE WHITE CITY PEDESTRIAN CROSSING VIBRATION

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Abstract: *The article presents the structural analysis of a cable stayed pedestrian crossing (hereinafter it will be called structure) to be erected in the White City region of Baku. The deformation scheme of the strucutre has been investigated. The results of the study of dynamic forces acting on the structure are illustrated. The structual analysis for the first three vibration modes, resonant and dynamic stability has been performed.*

Keywords: *shafts, pedestrian crossing, dynamics, pylon, wind load*

1. INTRODUCTION

The construction of overpasses and pedestrian crossings play a crucial part in the expansion of urban infrastructure and increase the welfare of pedestrians. The pedestrian crossing erected in the White City is the most appropriate sample for this. The structure was designed with one pylon, steel deck and cables on the both sides of deck. The structure was designed by "Hydrotrans Engineering" and is being built by "Evrascon" company. Considering that the area where the crossing is located is close to the coast of the Caspian Sea, that is, in a windy region, and considering the height of the pylon (75 m), the study of the dynamic forces affecting the structure and the dynamic behavior of the crossing become an important issue. The lastest view of structure, erection of pylon during construction and longitudinal section are shown in the below figures.

a)

b)

c)

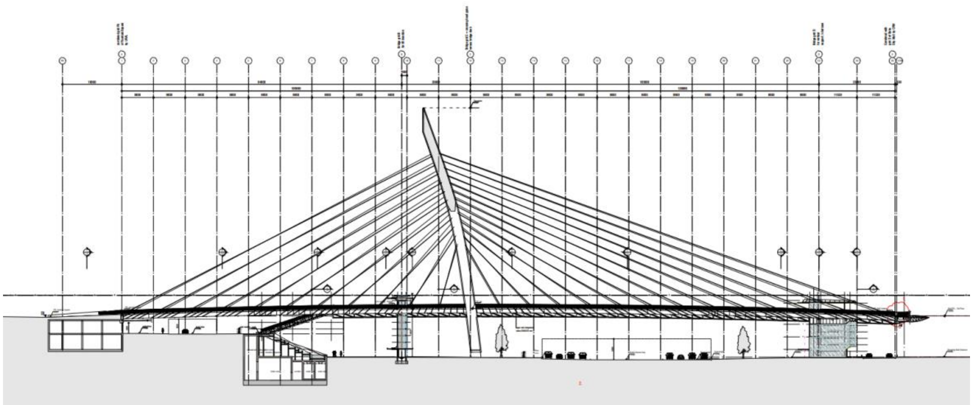

Figure 1. General view of White city cable stayed pedestrian crossing *(a)*, erection of pylon *(b)* and longitudinal section *(c)*

2. STUDY OF THE STRESS-STRAIN STATE OF THE PEDESTRIAN CROSSING

Due to the influence of loads, it has been observed that the metal stiffener beam and the metal pylon with a tubular cross-section bend, and the cables work in tension (see Fig. 2). Here, self-weight is considered as a permanent load affecting the structure and human crowd load, wind load, the possibility of collapse of bridge piers, and seismic impact are considered as live loads. Analysis was performed based on AzDTN, EN norms and AASHTO official document.

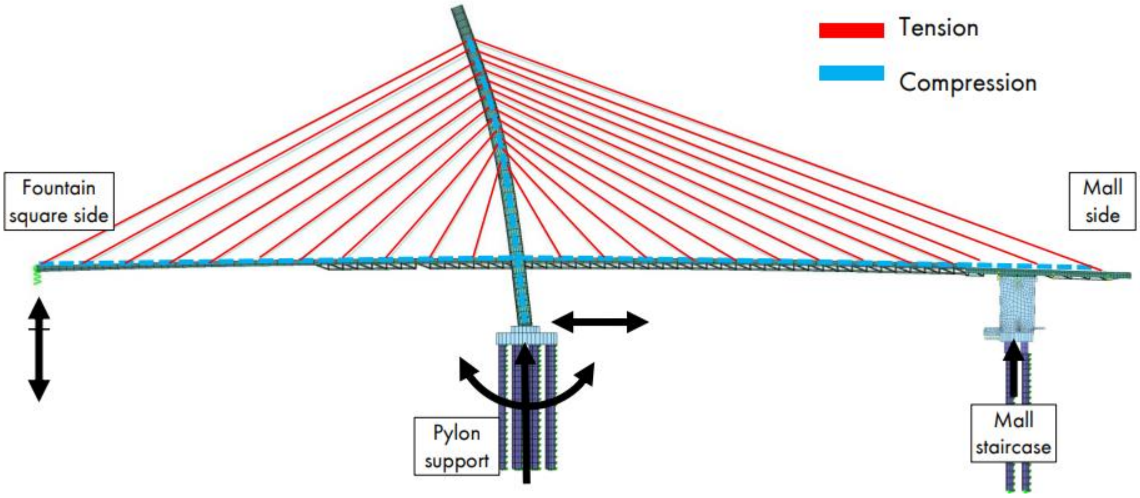

Figure 2. Reactions of structure support

The wind load causes mainly the vibration of stiffness beam of structure by affecting the pylon and cables. Separately, the cables are affected by: the tension force of the cable, its own weight, the relaxation reaction, the horizontal effect of the wind, the reaction caused by it, the horizontal movement caused by the wind on the beam, and the aerodynamic Carman vortex waves (vortex shedding) created on the opposite side.

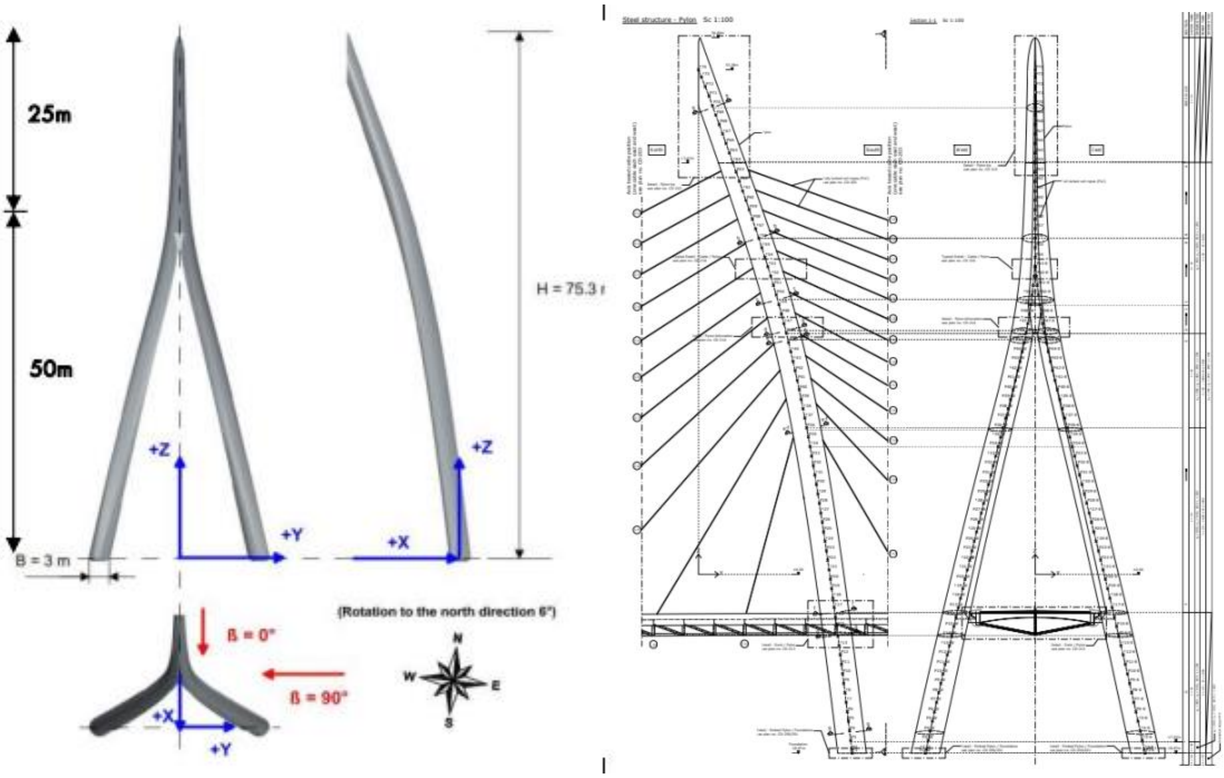

Figure 3. The scheme of the pylon and the connection points of the cables [6]

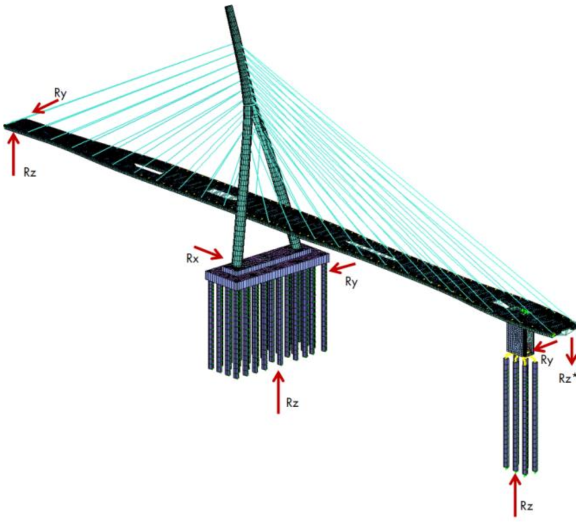

Figure 4. 3D analysis model of structure [6]

Cableas are attached to the pylon rigidly and fixed to the stiffness beam with elastic dampers. Horizontal and vertical support reactions generated in the supports are marked in Figure 4. Vertical reaction (Rz) and horizontal reactions (Rx , Ry) occur in the pylon, which is considered the main support of the pedestrian crossing.

3. DYNAMIC MODEL AND ANALYSIS OF STRUCTURE

The wind load acting on the structure mainly moves the cables causing the stiffener beam to dance. The cables and the stiffness beam begin to sway due to the aerodynamic force. These movements are mainly vertical and horizontal. The most dangerous here is the vertical oscillation of the stiffness beam. The differential equation can be written as follows:

$$M\ddot{u} + C\dot{u} + Ku = -F_{eff} \quad (1)$$

Here, M is the mass of the dynamic system; C - extinguishing characteristic; K - stiffness of the system; u,(u,) ̇ u ̈-displacement, speed and acceleration respectively; F_{eff} - dynamic force acting on it. When solving the problem by the finite element method, we can write the equation of free oscillations as follows:

$$[M_i][\ddot{u}_i] + [C][\dot{u}_i] + [K][u] = 0 \quad (2)$$

Here [M], [C], [K], [u] are the mass, damping, stiffness and displacement matrices, accordingly.

The first and second frequency of vertical vibration can be determined from below formula:

$$\omega_{v,i} = \sqrt{A_i \times \frac{g}{H_p} \times \frac{E_v}{R_v} \times \frac{(p+v)}{p} \times \frac{n}{\left[1+\frac{(n-1)^2 l^2}{4n^2 H_p^2}\right]}} \quad (3)$$

Here A_i is the coefficient for the i dance form, $A_1=0.35$; g – free fall acceleration ; H_p - the height of the pylon, H_p =75 m; E - modulus of elasticity of the cable, $E=1.6\times105\ mPa$; p - constant load on the crossing beam, *p=78.5 kN/m*; v - temporary load on the crossing beam, *v=31.02 kN/m;* n - the number of panels in one deck, *n=24*; l – maximum span, *l=109 m*.

For the first mode (i=1, A1=0.35), the frequency of vertical oscillation is $\omega_{v1}=2{,}385$ *rad/sec*. Then the period will be:

$$T_{v1}=\frac{2\pi}{\omega_{v1}}=2{,}633\ sec \tag{4}$$

For the second mode *(i=2,* $A_2=1{,}25$*)* the frequency of vertical oscillation is $\omega_{v2}=4{,}508$ *rad/sec*.

$$T_{v2}=\frac{2\pi}{\omega_{v2}}=1{,}393\ sec \tag{5}$$

The resonance period for automobile bridges and cable stayed pedestrian crossings is T_v=(0.45-0.6). In the first and second mode of vertical oscillations, the period remains outside the resonance range.

The frequency of horizontal oscillations for the third mode (i=1,2,3):

$$\omega_{h,i}=\sqrt{\frac{i^4\pi}{l^4}\frac{EI_h}{m}+\frac{g}{H_p}} \tag{6}$$

Here I_h is the moment of inertia in the horizontal direction of the stiffness beam, $I_h=7.82\ m^4$; *E=2.06×107 mPa; m=p/g=(78.5+31.02)/9.81=11.16 t/m* mass of 1 pogon meter of the beam.

For the first mode (i=1), the frequency of oscillations in the horizontal direction is $\omega_{h,1}=0.41$ *rad/sec* and the period:

$$T_{h1}=\frac{2\pi}{\omega_{h1}}=\frac{2\times 3{,}14}{0{,}41}=15{,}31\ sec \tag{7}$$

For the second mode (i=2), the frequency of oscillations in the horizontal direction is $\omega_{h,2}=2{,}289$ *rad/sec* and the period:

$$T_{h2}=\frac{2\pi}{\omega_{h1}}=\frac{2\times 3{,}14}{2{,}289}=2{,}743\ sec \tag{8}$$

For the third mode (i=3), the frequency of oscillations in the horizontal direction is $\omega_{h,3}=5{,}099$ *rad/sec* and the period:

$$T_{h3}=\frac{2\pi}{\omega_{h1}}=\frac{2\times 3{,}14}{5{,}099}=1{,}231\ sec \tag{9}$$

Period values of horizontal oscillations are outside the range of critical value Th=(0.9-1.2 s).The period of both oscillations mode does not reach the critical value for all modes.

4. CHECKING THE AERODYNAMIC STABILITY OF THE STRUCTURE

The main condition of the study is the generation of aerodynamic waves during the critical wind speed:

$$V_{cr} > 1{,}5V_p \quad (10)$$

Here V_p*=45 m/sec* maximum wind speed in the construction site. The critical speed is determined by the following formula:

$$V_{cr} = V_{cr..m} \times \omega_t \times B \quad (11)$$

Here B=14.6 m - the maximum width of the pedestrian crossing; $V_{cr,m}$*=8.0 m/sec* critical speed determined on the model. Frequency of rotational oscillations $\omega_t=2.5\omega_{v1}=2.5\times 2.385=6.96$ *rad/*sec. The frequency of the first mode of vertical oscillations is $\omega_{v1}=2.385$ *rad/sec.*

$$V_{cr} = 8{,}0 \times 6{,}96 \times 14{,}6 = 812{,}9\, m/sec > 1{,}5 \times 45 = 67{,}5\, m/sec \quad (12)$$

The aerodynamic stability condition is within limit.

Results

1. In addition to the permanent and temporary loads affecting bridges and pedestrian crossings, the wind load and the resulting aerodynamic effects must be taken into account in the calculations;
2. In the dynamic analysis of the structure, the vertical and horizontal frequency and period should be calculated for the first three oscillation modes and the resonance limit should be determined. In the article, based on the analysis, the dynamic stability of the White City pedestrian crossing has been confirmed;
3. The stiffness of the structure depends on the connection of the cables to the pylon and the main stiffness beam acting in bending. The connection of dampers used here can change the overall stiffness and analys scheme.

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