



MODELLING AND STATIC ANALYSING FOR A CABLE STAYED BRIDGE CONSIDERING THE CONSTRUCTION STAGES

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Abstract

This paper presents the results, in terms of forces and displacements, during the construction process of a cable-stayed bridge over the Dâmbovița River in Bucharest. To determine the stress-strain state in the structural elements, a 3D finite element analysis model was developed. For modeling the superstructure, a planar grillage was created and finite elements used were straight space beams with two nodes and six degrees of freedom for each node: three translations and three rotations. To model the concrete slab, plane finite elements with 4 nodes were used, exhibiting both plate and membrane behavior. In the static analyses conducted considering the construction stages, characteristic and frequent actions were considered according to Eurocode standards for load combinations. The main purpose of the conducted analyses was to monitor the internal forces and displacements in both, the cables and the superstructure elements, as well as in the pylons and their foundations. The results of the nonlinear analyses conducted in construction stages have indicated that the chosen construction technology is suitable, and the safety level achieved for the structure is appropriate.

Keywords: cable-stayed bridge, stress-strain state, construction stages, model, analysis

1 General presentation

To avoid the collapse of the bridges during construction, the engineers should take into consideration, while designing the bridge, the forces and displacement of the structure for every construction stage. In this study it has been analysed the stress-strain state and the deformation in the structure of Ciurel Bridge. The stress-strain state has been studied and analysed in the deck and cables, while the deformations had been studied as total deformation of the structure and of the pylons.

1.1 Design data

Ciurel Bridge is part of the project “Urban expressway Splaiul Independenței-Ciurel-Motorway A1, Bridge over Dâmbovița River in Ciurel interchange” on one way [1].

The bridge has a total length of 235.20 m. It was designed to have two asymmetrical spans, the first span having a length of 69.50m and the second one having a length of 164.70m [2]. The total width of the bridge is 13.90 m, having three roadways, each having the width of 3.50 m and two sideways, with the width of 1.25m each [1].

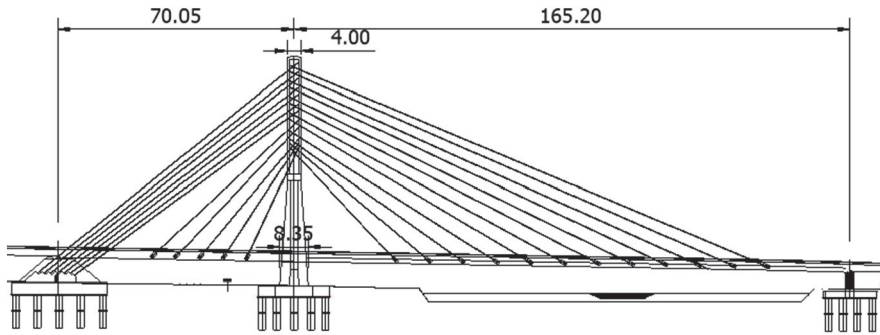


Figure 1 Longitudinal View

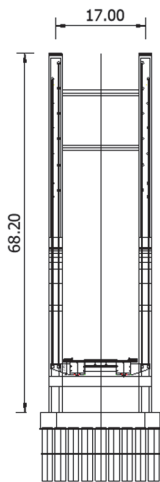


Figure 2 Cross section View

The superstructure is a composite superstructure, with two closed steel boxes and a monolith concrete composite [3]. The boxes are 2.80m wide and it have a height of 2.50m each. The distance is 8.70m between the two boxes' axes [1].

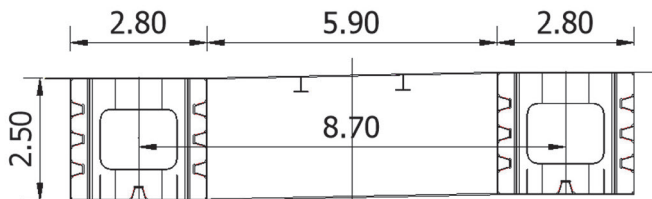


Figure 3 Deck Cross Section View

The cables are arranged in two planes and the layout form is in harp [4]. There is a dozen of pairs, but the distance between each pair is different [5]. The pylon has the shape of "H" letter, with other two transversal cross beams to increase the torsional resistance [6]. They have a variable section on their height, which is 30.80m (Fig. 1).

The bridge has deep foundations, with piles having a diameter of 2.00 m and length of 18.00m for the anchorage block and 32.00 m for the pylon. It was designed for the seismic zone 8_p, being characterised by a corner period $T_c = 1.6$ s and a peak ground acceleration value $a_g = 0.24$ g, according to the Romanian normative P100-1/2006 and the Romanian normative SR 11100/1-93 [1]. The bridge is placed in Bucharest nearby Lacul Morii dam [1].

2 Model, Construction stages, Characteristics and Loads

2.1 Model

For the static analysis of the 3D model the Finite Element Method (FEM) was used. For the model of the superstructure a planar grillage was created and finite elements used were straight space beams with two nodes and six degrees of freedom for each node: three translations and three rotations. To model the concrete slab, plane finite elements with 4 nodes were used, exhibiting both plate and membrane behavior [7, 8]. The longitudinal elements represent the two boxes and the strut. The transversal elements represent the transversal cross beams between the two boxes [8, 9]. The analyse was a nonlinear construction stages one. Every construction stage takes into account the previous deformed shape of the structure. Also, the nonlinear behaviour of the cables was taken into account.

2.2 Construction stages

There were forty construction stages considered, according to the design project. The first stage was the construction of the foundations, the pylon and the anchorage block [1]. The next thirty-four consist of the mounting of the sections of the deck on temporary towers and welding of the boxes with the transversal and longitudinal beams, the casting of the deck reinforced concrete slab in sections of the deck in compression, the welding of the supporting brackets for the cables, the montage and tensioning of the cables [1]. In the 37th stage the final tensioning of the cables, the montage of the guardrail beam and the casting of the deck reinforced concrete slab on the rest of the deck are done [1]. In the 38th stage, the casting of the carriageway, and the montage of the guardrail and the pedestrian parapet are done [1]. In the 39th stage the temporary piers are demolished and in the 40th stage the tension in the cables is balanced in order to obtain the desired final geometry of the deck [1]. For the 3D model, the stages have been combined and only 17 stages have been considered [10, [11].

2.3 Materials

The concrete used for the elevation, foundations, the deck reinforced concrete slab and the piers is C35/45 and the steel used for the deck and the longitudinal and transversal beams is S355 NL. The characteristics for the materials used in modelling were according to standards in use [12].

2.4 Actions

The actions that were considered for the analysis are: the dead load, which is automatically evaluated by the program, based on the input consisting in the geometry of all elements cross sections; the load of the new casted concrete; the load of the pavement and the normal load of the tensioning of the cables. These actions were activated in the finite element model corresponding to each construction stage [13]. All the loadings have been combined according to the standards in use, using the partial safety factors [12, 14].

3 Results

Following the nonlinear staged construction analyses, the stress-strain and deformations state corresponding to each construction stage was obtained. This type of analysis allowed to define the construction stages and the sequential loading of the structure. The analyses results are shown in the following graphs.

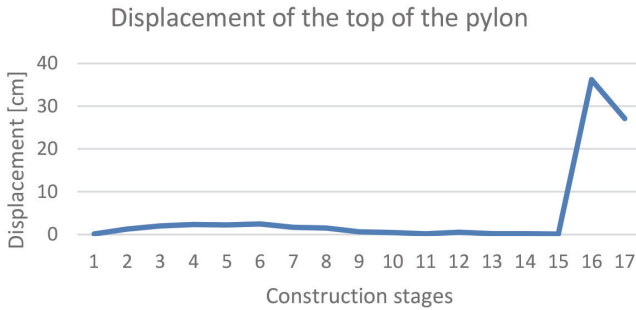


Figure 4 Displacement of the top of the pylon

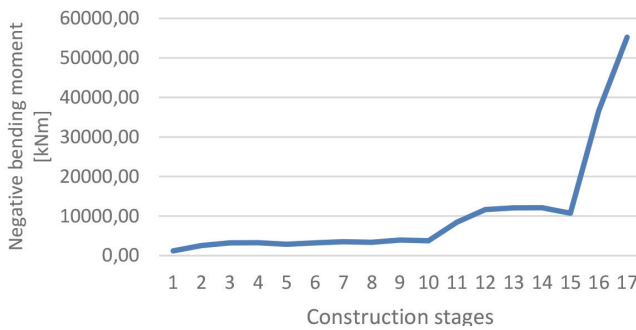


Figure 5 Negative bending moment in the deck, in the middle of the largest span

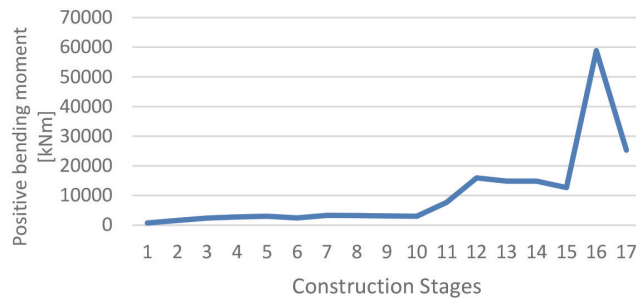


Figure 6 Positive bending moment in the deck, in the middle of the largest span

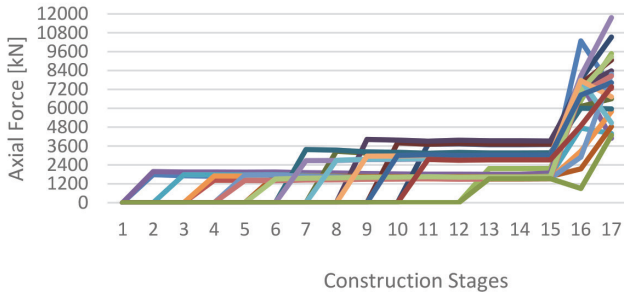


Figure 7 Evolution of the Axial Forces in the cables on the deck right side on both spans

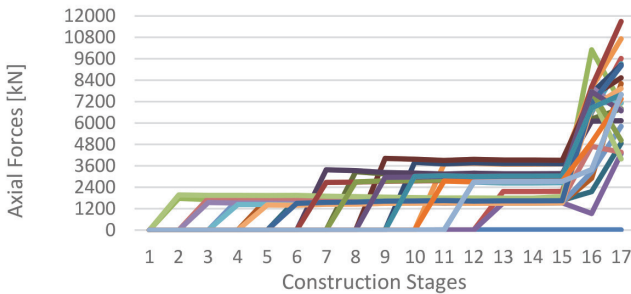


Figure 8 Evolution of the Axial Forces in the cables on the deck left side on both spans

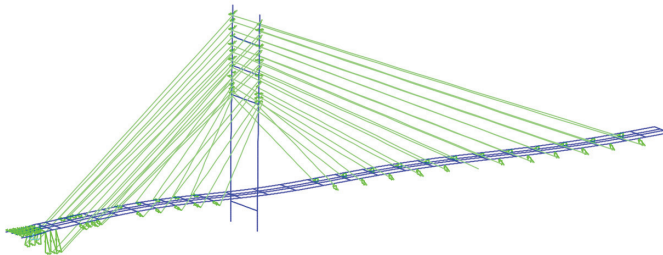


Figure 9 The deformed shape of the bridge in the last construction stage

4 Conclusions

The method presented in this paper emphasizes the importance of taking into consideration the construction stages during design in order to anticipate possible problems during construction. The displacement values and the stress-strain state values can dictate the construction method and if there are any problems the method allows to simulate the impact of necessary modifications and adaptations to be done to the structure. The low values of the bending moment in the deck and the pylon proves that the construction method adopted is appropriate (Fig. 4, Fig. 5 and Fig. 6). The construction method allows the limitation to low and very low values of the displacement of the deck, of the stresses and the strains (Fig. 4, Fig. 5 and Fig. 6). Using the bridge bents while constructing the bridge permits the limitation of the displacement of the top of the pylon and the axial forces and bending moment at the base of the pylon (Fig. 4, Fig. 5 and Fig. 6).

The maximum value of the displacement, for the last construction stage of the pylon is about $H_{\text{pylon}}/250$. This value is within the recommended limitations prescribed by the norms. The cables have been tensioned in two stages, thus having a better control of the displacements of the deck and pylon. To obtain the deck camber, some cables have been tensioned in one stage and other in two stages. The Figure 7. and Figure 8. show the way the cables started working in different construction stages and the tendencies of the axial forces to self-leveling depending on the general deformation of the structure. The initial value of the axial force in the cables is 2000 kN and the final value is 1180 kN. In Figure 9. it can be observed the camber of the superstructure in the final stage to keep the deflection of the superstructure during service. In the graphs in figures 7 and 8 it can be observed that the variation of the values of the axial forces in the cables is small. This proves a good behaviour of the structure, reducing the possibility of cable de-tensioning.

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