

THEORETICAL-EXPERIMENTAL STATIC AND DYNAMIC ANALYSIS OF DOUBLE LAYERED CATENARY

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Abstract. The paper presents the results of static and dynamic tests of double layered catenary of the swimming pool building roof in Leskovac. By the comparison of measured and calculated values, a potential was created to correct the mathematical model, and to verify it. Only then, the calculation model for all sorts of static and dynamic load was able to simulate the realistic behavior of the structure. In this paper, the authors presented the basic recommendations in terms of what initial tensile force should be adopted in order to control the stability of such very cost-effective girders.

Key words: Suspended systems, cable truss, dynamic analysis, structure testing.

1. INTRODUCTION

The swimming pool room of the Sport and recreational complex "Zdravlje" in Leskovac has a span of 60m, and the roof structure was constructed of the double layered catenaries in vertical plane – pretensioned cable truss with diagonal members (figure 1). Insufficient forces of pretensioning may result in the instability of cable trusses.

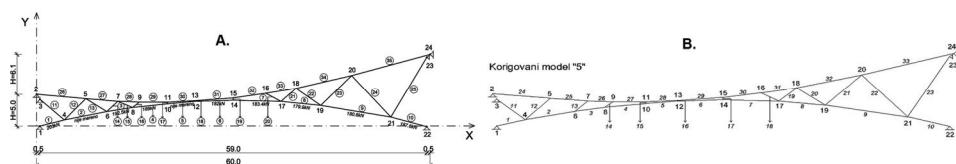


Fig. 1 Configuration of the design model: A. Non-corrected, B. Corrected V

2. FORMATION OF STABLE DOUBLE LAYERED CATENARY

Static analysis of double cable truss girders for the potential combinations of loads yields forces in the girder members, as well as displacements in respect to the reference position. Analysis of losses due to the pretensioning forces provided the value of the initial tension force and dilatation of stabilizing cable.

The pretensioning force is accomplished by tensioning the lower cable and anchoring it by a special anchor. The cable tensioning is carried out after the coordinates of the nodes in zero position of the structure (without load and pretensioning) have been geodetically measured.

The structure parameters which were verified on the spot in this particular case were: dilatation of the lower stabilizing cable, forces in the end members of the stabilizing cable measured by a special mechanical instrument (fig. 2) and vertical displacement of the medium point of cable truss in respect to the "zero position".

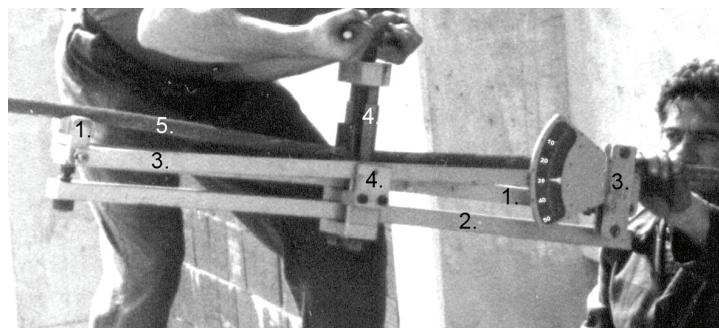


Fig. 2 Instrument "Amsler" for measuring of forces in cables

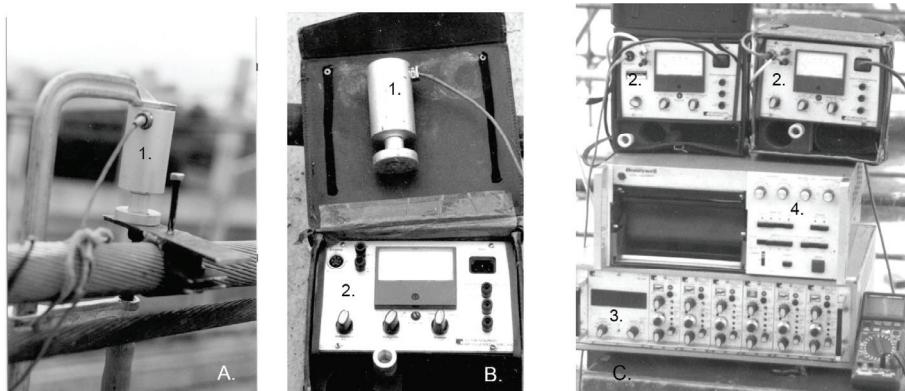


Fig. 3 A) Impulse emitter of the SMU 300 instrument attached to the structure,
B) Inertial measuring instrument SMU 300, C) Measuring station of the
instrument, impulse amplifier and oscilloscope

By comparison of the measured forces in the end members of the stabilizing cable of all double layered cable trusses and the measured values of the corresponding vertical displacements of their medium nodes, with the appropriate, theoretically calculated values, a congruence was established, ranging between 95% and 100%.

A special attention was paid to the medium cable trusses, because out of all eight cable trusses its chord was the smallest, but the pretensioning force in the stabilizing cable was the highest. Because of that, the forces in the stabilizing cable were carried out, as well as the recording of the geometry of the cable truss girder and the characteristic vibrations of the girder. The dynamic examination of the girder was carried out the inertial dynamic instruments (Fig. 3).

3. EXPERIMENTAL RESULTS AND CORRESPONDING THEORETICAL VALUES

Procedure of verification of the calculation model in respect to the real structure whose "response to pretensioning" was obtained by the measurement in situ was accomplished by comparing the results obtained by static measurement on the cable truss to the results obtained by the finite displacement method. The differences in the displacements of nodes and forces in the members (fig. 4.A, 5.A and 6.A) were determined. The theoretical results are obtained by the application of program modules whose author is Dragan Kostić: CABL-T (calculation of girder geometry and the forces in members according to an analytical method), CABL-TP (pre-processor for entry of data into MKP) and CABL-N (calculation of girder geometry and forces in members according to the finite displacement method) [4].

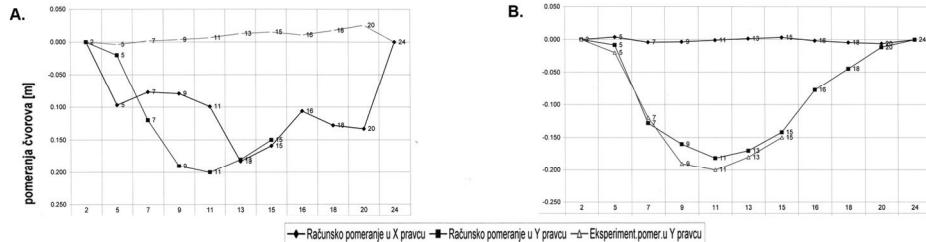


Fig. 4 Comparative diagram of node displacement in the upper - bearing cable (theoretical, experimental data): A. Not-corrected calculation model, B. Corrected calculation model "5"

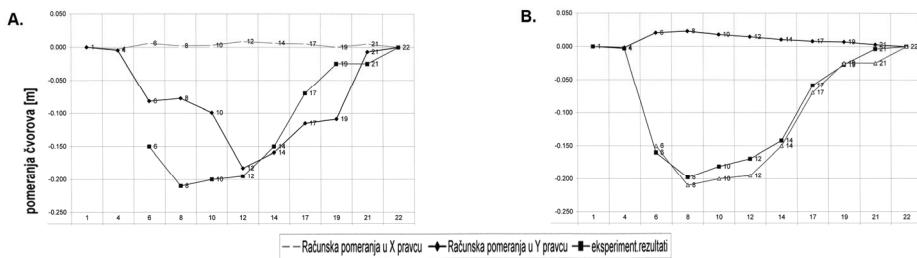


Fig. 5. Comparative diagram of node displacement in the lower - stabilizing cable (theoretical, experimental data): A. Not-corrected calculation model, B. Corrected calculation model

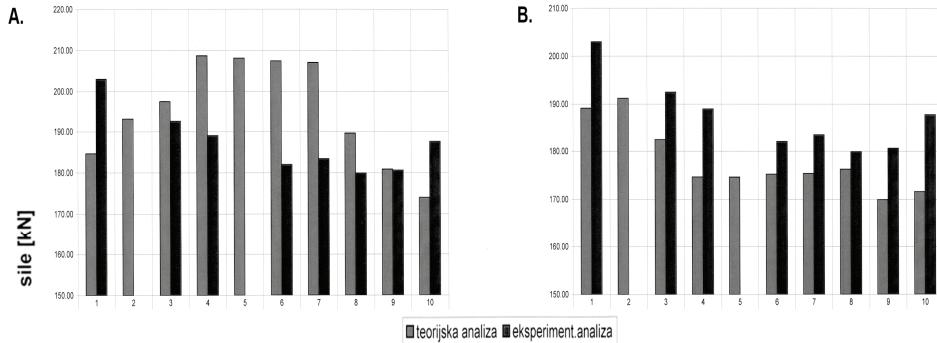


Fig. 6 Comparative diagram of forces in the members of lower – stabilizing cable
 (theoretical, experimental data): Not-corrected calculation model,
 B. Corrected calculation model

4. CORRECTION OF THE BASIC CALCULATION MODEL

Basic calculation model reflects the real model in unloaded state in terms of its configuration and geometry (Figure 3.A). Surveying the structure and comparison of measured and calculation results clearly demonstrated that some of the diagonal ties are "inactive", thus the node displacement would not result in the expected smooth curve, neither for the bearing nor for the stabilizing cable.

Due to the geometrical non-linearity of the "response" of the structure, its multiple static indeterminacy, assumed pretensioning forces, several corrected calculation models have been formed. Each of the corrected models contains members which do not participate in redistribution of pretensioning forces which are entered into the stabilizing cable. Values on the altered models were analyzed and compared to the measured values. The criterion for adoption of the calculation model is congruence with the experimental data ranging between 85% and 100%.

Five calculation models which were corrected by exclusion of certain members of the web have been analyzed in detail. Theoretical results of the corrected calculation model (figure 1. B) which exhibited the highest discrepancy with the test results, verified the calculation model (Figure 4.B, 5.B and 6.B) [4].

5. DIAGNOSTICS OF DYNAMIC PARAMETERS

The dynamic properties favorable for comparison with the experimental data for the corrected mathematical model "5" were acquired. The dynamic testing, conducted with two inertial instruments yielded the following accelerograms (fig. 7).

A fast Fourier transform was used to calculate the energy of spectral density implementing the complex conjugation, that is, the energy values of varied frequencies were obtained. The graphic presentation of the amplitude spectrum in the function of the frequencies clearly distinguishes dominant oscillation frequencies (fig. 8). Data obtained in this manner are suitable for comparison with the calculation results.

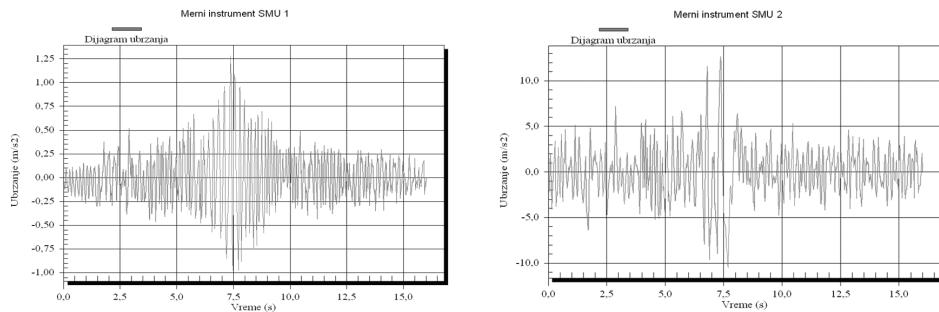


Fig. 7 Vibrations of the catenary drawn according to the data decoded from the graphic records of the accelerometers SMU-1 and SMU-2 in the nodes 9 and 13 of the bearing cable

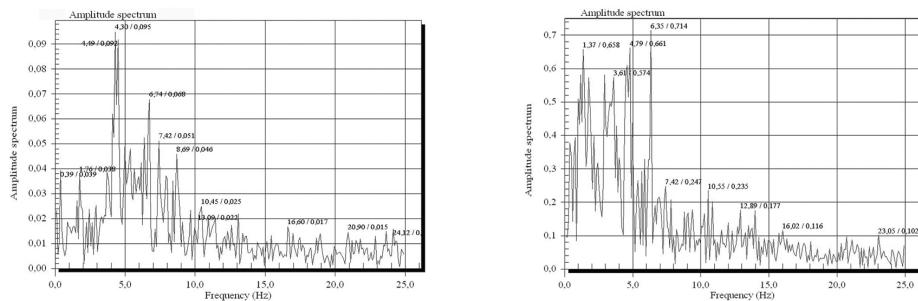


Fig. 8 Frequent spectrum obtained by FFT analysis of the SMU 1 and SMU 2 accelerograms in the node 9 and 13 of the bearing cable

The calculation data have been obtained by the software package "AnSys", through a modal analysis by the inverse iteration method. Static and dynamic responses of the adopted corrected basic numerical model in comparison to the experimentally obtained results are in agreement in the range of statistic reliability (90% do 100%).



Fig. 9 Tonal forms of characteristic vibrations in vertical plane of cable truss of the swimming pool in Leskovac, obtained by calculation procedure – software package "AnSys"

Table 1 Frequencies and periods of dominant tonal forms obtained by FFT analysis and calculation analysis

| | Tonova forma | I | II | III | IV | V | VI | VII | VIII | IX | X |
|-------------------------|---------------------------------|------|------|------|------|------|------|------|------|------|------|
| SMU-1 | Frequency Hz | | | | | 4.30 | | 4.49 | | 6.74 | |
| | Period sec. | | | | | 0.23 | | 0.22 | | 0.15 | |
| SMU-2 | Frequency Hz | | | | | 3.61 | | 4.79 | | 6.35 | |
| | Period sec. | | | | | 0.28 | | 0.21 | | 0.16 | |
| Calculation analysis RA | Frequency Hz | 1.15 | 2.03 | 2.89 | 3.76 | 3.91 | 3.94 | 5.16 | 5.22 | 5.98 | 6.06 |
| | Period sec. | 0.87 | 0.49 | 0.35 | 0.27 | 0.26 | 0.25 | 0.19 | 0.19 | 0.17 | 0.16 |
| Departure % RA/SMU-1 | % | | | | | 9.1 | | 14.9 | | 11.3 | |
| Departure % RA/SMU-2 | % | | | | | 8.3 | | 7.7 | | -5.8 | |
| Oscillation direction | Z ³ , Y ⁴ | Z | Z | Z | Z | Y | Z | Y | Z | Y | Z |

³ Z direction is perpendicular to the vertical plane of the girder,

⁴ Y direction is in the vertical plane of the girder

6. ANALYSIS OF RELIABILITY OF IMPLEMENTED CALCULATION METHOD

Experimentally obtained results (forces, displacements, and frequencies) represented the basis for theoretical analysis on the mathematical model which will, according to its geometrical and physical characteristics have complete similarity to the real model – prototype of the tested structure. Static and dynamic response of the adopted mathematical model, in comparison to the experimentally obtained results, are in agreement in the range of statistic reliability (90% do 100%). Eo ipso, it can be stated that the adopted and implemented calculation methodology is easily applicable to the class of problems which were being solved here.

The implemented combined analytical-iterative procedure demonstrated that n analysis of similar models can be quickly and reliably conducted, with the correction of entry parameters. The results of static parameters (forces in the members and displacements) and comparison of characteristic maximum and minimum values, have been obtained through implementation of program modules CABL-T, CABL-TP and CABL-N, while the dynamic characteristics of the structure (characteristic and forced frequencies) have been obtained through implementation of the software package AnSys or some other with similar characteristics (ESA-Prima Win, Straus, Lusas, Diana...).

7. CONCLUSIONS

The conducted analyses in this chapters 3 to 5 identify the practical working steps in calculation and analysis of cable trusses [4]:

- (1) Adoption of global geometry of girders, physical constants and dimensions of bearing elements and loads which will act on the structure,
- (2) Previous calculation of cable trusses with the usage of program modules CABL-T and CABL-TP,
- (3) Static calculation with the usage of the program block CABL-N,
- (4) Dynamic calculation of modal, harmonic and transient vibrations through implementation of ANSYS or some other software with similar characteristics.

Calculations conducted in this manner yield reliable results which are very close to static and dynamic response of the structure prototype and have quick convergence to the solutions (phases 2, 3 and 4). In the design phase, these results provide the control of tension force and reduction of unpleasant vibration of cable truss. Thus directly control the stability of these structures.

The preparation phase (1) depends exclusively on the degree of knowledge, experience and skill of the designer.

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TEORIJSKO-EKSPERIMENTALNA STATIČKA I DINAMIČKA ANALIZA DVOPOJASNE LANČANICE

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U radu su prikazani rezultati statičkog i dinamičkog ispitivanja dvopojasne lančanice bazena u Leskovcu. Poređenjem merenih i računatih vrednosti stvorena je mogućnost da se izvrši korekcija matematičkog modela, a zatim i njegova verifikacija. Tek nakon toga računski model za sve vrste statičkog i dinamičkog opterećenja potpuno realno je simulirao stvarno ponašanje konstrukcije. U okviru ovog rada autori su dali osnovne preporuke u pogledu usvajanja početnih sila zatezanja u cilju kontrole stabilnosti ovakvih vrlo ekonomičnih nosača.

Ključne reči: Viseći sistemi, kablovska rešetka, dinamička analiza, ispitivanje konstrukcija