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MEASUREMENT AND CONTROL OF THE REACTION FORCES OF A REINFORCED CONCRETE BOX GIRDER BRIDGE CONSTRUCTED BY INCREMENTAL LAUNCHING

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Abstract

The measurement and control of the reaction forces of a three-span 114.5 meter long reinforced concrete box girder bridge built by incremental launching is reviewed. Using the complex lifting and measuring system it was possible to determine the effective dead load of the bridge during the lifting at eight points. By means of the observed alteration of the reactions suitable to the different values and combinations of the vertical displacements it was possible to calculate the proper vertical position of the bearings answering the designed reaction forces. The 22 % difference between the reaction forces of the designed and launched structure justified the necessity of checking. The decsease of the deviations under a 1 % limit proved the suitbility of the measuring system and the method applied.

Keywords: incremental launching, measurment of the reaction forces.

The bridge over the Berettyó river in Berettyóújfalu built in 1989 was the first prestressed concrete bridge in Hungary constructed by the technology of incremental launching. The superstructure is a parallel flanged 12.00 meter wide box girder with the spans 32.25 + 50.00 + 32.25 meters. The whole bridge was constructed in 12 sections, in general, 10.0 meter long each. The design and construction works were made by the Hídépítő Bridge Construction Company. The sections were manufactured on fixed prefabricating scaffolds. The prestressing works and the incremental launching went on by the applied techniques and technology without any problem. The manufacturing of the 10 meter long sections were carried out by maintaining the one week cycle period. The detailed review of the bridge may be found in [1]. Because of the new technology not applied in Hungary till now and the small deflections of the prefabricating scaffold during the manufacturing process, the control of the shape of the launched structure, in other words the checking of the appropriate vertical position of the supports seems to be necessary. The deviations from the designed vertical

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position cause in the structure unwanted excess internal forces. Reliable supervision is possible only by measuring the reaction forces. The structure is in the design state when the effective reaction forces are compatible with the computed values.

Placing of the superstructure from the sliding supports to the permanent supports and setting the geometrical values assuring the designed support force distribution were evaluated by the help of a till now not applied complex of measuring and lifting system. The system was developed by the cooperation of the Department of Reinforced Concrete Structures, TUB and the Hídépítő Bridge Construction Company, assembled from hydraulic lifting devices, electric force and displacement measuring tools and makes possible the lifting of the whole superstructure and the simultaneous measurrement of the support forces and the support displacements.

Description of the Measuring System

When assembling the measuring and lifting system, the following requirements should be satisfied:

- measuring the effective reaction forces of the bridge leaning on the sliding supports;
- measuring the alteration of the effective reaction forces due to the unit vertical support displacement;
- determination of the differences between the designed and the effective support force distribution;
- evaluation of the necessary vertical support displacements to achieve the designed support force distribution.

To satisfy these requirements, the simultaneous the reaction forces and the belonging vertical displacements at the abutments and at the piers (on 4 – 2 places) was necessary.

The lifting and vertical moving of the whole bridge took place by the hydraulic lifting system settled and operated by the Hídépítő Bridge Construction Company. On the piers 2 pieces of jacks 500 tons capacity and on the abutments 2 pieces of jacks 200 tons capacity each, operated in pairs by one pump were placed.

The reaction forces were measured at every lifting point by electric force measuring cells placed between the structure of the bridge and the presses. On the piers 2 pieces of 0–5 000 kN capacity and 1.5 kN sensitivity cells, on the abutments 2 pieces of 0–2 000 kN capacity and 0.4 kN sensitivity cells were set. All of the force measuring devices were designed and constructed at the Department of Reinforced Concrete Structures. The measuring accuracy of the cells was within –0.5 % in the whole working domain. Between the horizontally adjusted and centralized presses and the measuring cells spherical hinges were placed. The vertical displacements were measured by inductive displacement sensors type W–50 with the sensitivity of 1 μm. The signals of the electric sensor - transformers were recorded by electric measuring - amplifying devices. The positions of the measuring units and the hydraulic jaks are seen in *Fig. 1*.

Recordings

To improve the reliability of the data necessary for the vertical setting of the bridge, several lifting cycles were performed. In every lifting cycles, first of all, the whole bridge was lifted from the sliding supports at every support by 10–10 millimeters. In this position, which is equal the reaction forces to the position after launching to the sliding supports, all of the reaction forces at every lifting point were measured. These measuring data allowed to determine the effective reaction forces and their distribution and to evaluate the effective dead load (total mass) of the structure in the given state of construction as well.

The lifting cycles are shown in *Fig. 2*.

The Measured Data and Their Evaluation

The reaction forces determined from the statical calculations and the effective prestressed state were given by the designer (from the Berettyóújfalu side) as follows:

I	support (abutment)	1810 kN
II	support (pier)	8530 kN
III	support (pier)	8470 kN
IV	support (abutment)	1890 kN

The calculated total dead load is equal to 20 700 kN.

Evaluating the measured values the effective values of the support forces after every lifting cycle are included in the *Table 1*.

The data of the table show that the difference between the calculated and the effective dead load is hardly 2 % but the differences of the calculated and effective reaction forces vary in the range of 5–22 % . In order to balance the differences in the reaction forces indicated in the last row of the table, namely, in order to set the designed reaction forces, it is necessary to determine the proper vertical displacements on the supports. This calculation was carried out regarding the simultaneous evaluation of the

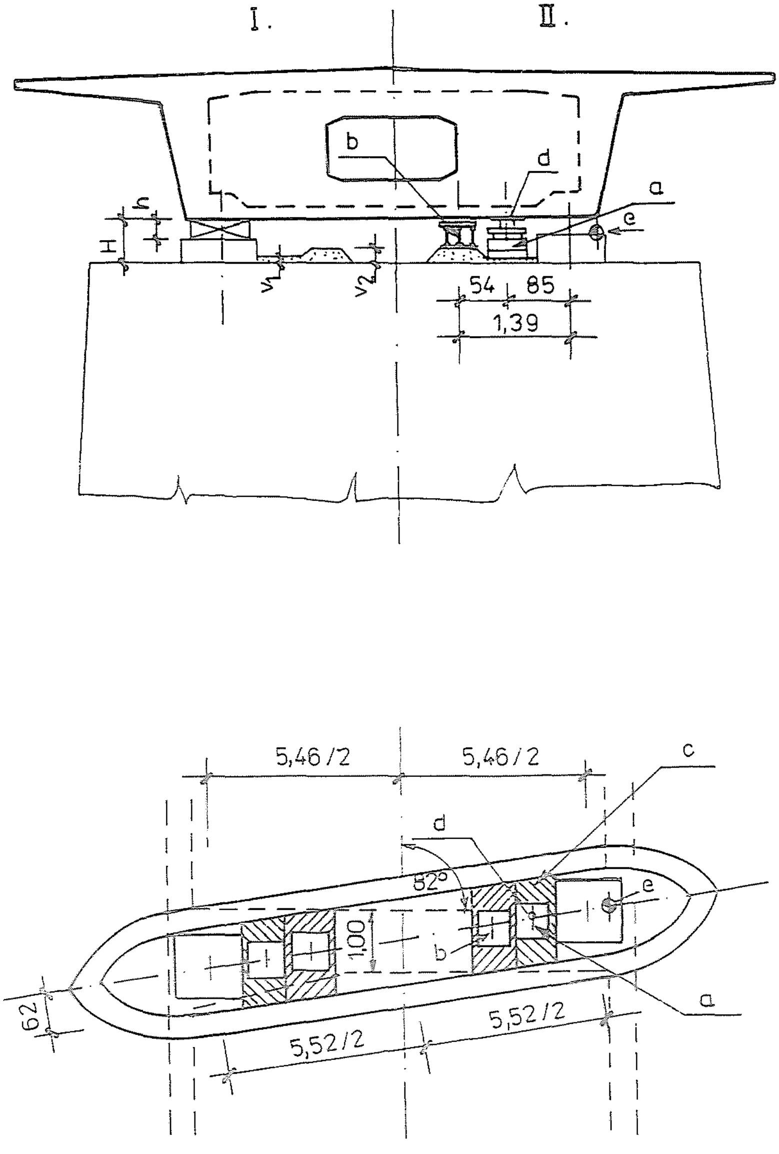

Fig. 1. Structural layout of the bridge
I. before lifting II. during lifting
a - hydraulic jack b - temporary bearing
c - cement mortar d - load cell
e - displacement gauge.

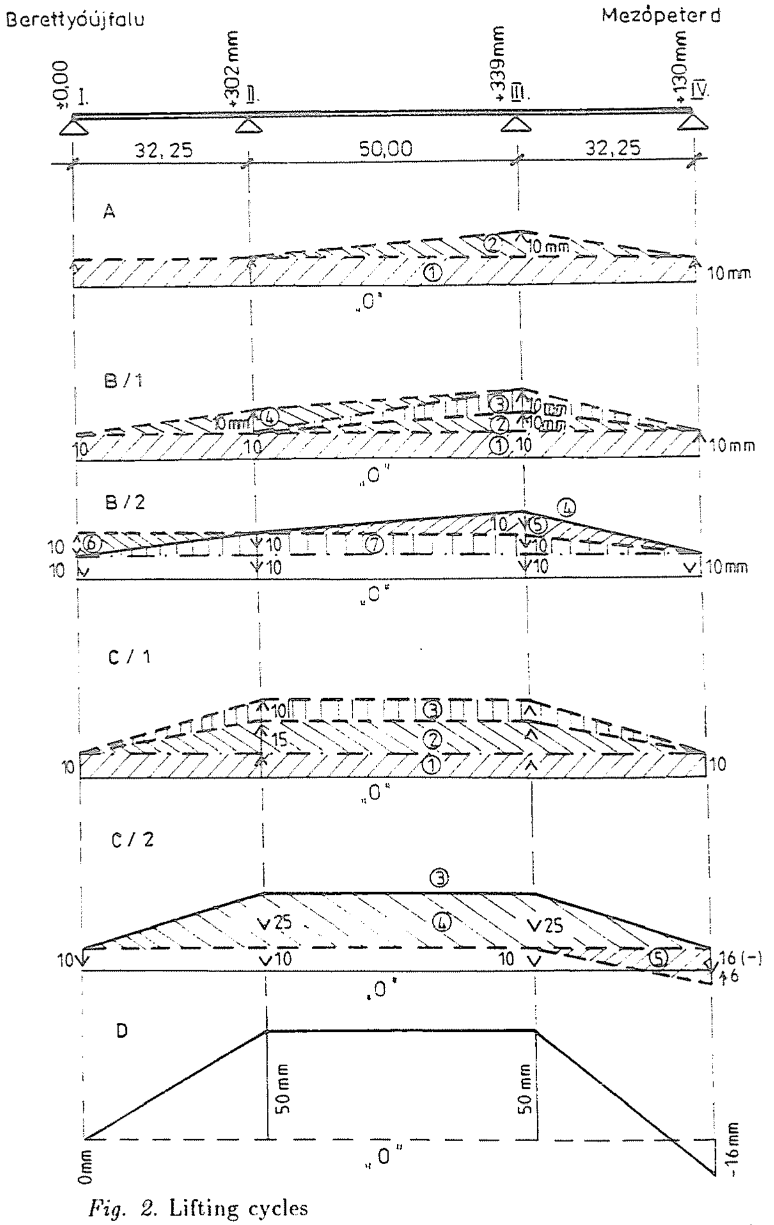

Fig. 2. Lifting cycles
'O' - basic position (the bridge on the sliping bearings)
A, B/1, B/2, C/1, C/2 - lifting cycles
D - final bearing heights

Table 1

	Number of the support				total
	I	II	III	IV	
	[kN]				
Measured reaction forces	2170	8000	7870	2260	20300
Designed reaction forces	1810	8530	8470	1890	20700
Designed reaction forces from the effective dead load	1780	8360	8310	1850	20300
The difference between the designed and the effective reaction forces (ΔP)	−390	+360	+440	−410	0

enforced vertical displacements and the alterations in the reaction forces during the lifting cycles.

The interaction of the displacements and the reaction forces is governed by the following set of linear equations:

$$\begin{aligned}
1.)\quad & a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 = \Delta P_1,\\
2.)\quad & a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + a_{24}x_4 = \Delta P_2,\\
3.)\quad & a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + a_{34}x_4 = \Delta P_3,\\
4.)\quad & a_{41}x_1 + a_{42}x_2 + a_{43}x_3 + a_{44}x_4 = \Delta P_4.
\end{aligned}$$

Taking the symmetry conditions and the Maxwell theorem (the equality of the coefficients) into consideration, the solution of the system can be transformed into the solution of the following reduced set of linear equations containing three equations each:

$$\text{I}\quad\left|\begin{aligned}
& a_{12}x_2 + a_{13}x_3 + a_{14}x_4 = \Delta P_1,\\
& a_{22}x_2 + a_{23}x_3 + a_{24}x_4 = \Delta P_2,\\
& a_{32}x_2 + a_{33}x_3 + a_{34}x_4 = \Delta P_3,\\
& a_{42}x_2 + a_{43}x_3 + a_{44}x_4 = \Delta P_4.
\end{aligned}\right|\quad\text{II}$$

Evaluating the measured data, the unit (10 mm) vertical displacement (lifting) causes the following effective support forces (in kN):

$$a_{11} = 8.2;\qquad a_{12} = -15.2;\qquad a_{13} = 9.0;$$
$$a_{22} = 28.3;\qquad a_{23} = -22.1;\qquad a_{14} = -2.0.$$

Setting of the Bridge

Because of the non-symmetric deviations of the reactions (ΔP_i) only an approximative compensation is possible. The following support-displacements – using the measured values of the cofficients (a_{ij}) result in the optimum state.

$$\text{I. case}\begin{cases} x_1 = & 0 \\ x_2 = & x_3 = 58.0 \text{ mm} \\ x_4 = & -8.0 \text{ mm.} \end{cases}$$

or

$$\text{II. case}\begin{cases} x_1 = -8.0 \text{ mm} \\ x_2 = x_3 = 50 \text{ mm} \\ x_4 = -16.0 \text{ mm} \end{cases}$$

Effectively the case II was carried out while the appropriate vertical position of the bridge was assured this way and the thickness of the available washers of the bearings matched to this solution most simply.

After this setting the effective reaction forces would be the following:

I	1820 kN
II	8300 kN
III	8350 kN
IV	1830 kN

The deviations from the designed values are under the accuracy limit of the measurement.

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