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Research paper

AUTOMATED SYSTEM FOR GEODETIC CONTROL IN BUILDING OF BRIDGE SUPERSTRUCTUTE CONSTRUCTIONS USING THE CANTILEVER CONCRETE OR ASSEMBLY METHOD

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Abstract

The article presents an automated system for geodetic control in building of bridge superstructure constructions using the cantilever construction method. The system includes two modules: an observation module consisting of a robotic total station and a portable laptop-tablet with special software and an assembly module connected via a radio interface. During construction, precise geodetic measurements are done to control the spatial status of the cantilever facility and the constructed bridge segments. The correction data are being registered into the total station and then transmitted to the assembly module. This procedure is repeated until the completion of the bridge construction. The author emphasizes the importance of precise measurements and proposes the development of a system with high-precision geodetic tools and means of communication thus providing fast and reliable data preparation for spatial orientation and automated preparation of executive documentation.

Key words: *Automated system, Geodetic control, Bridge superstructure construction, Cantilever method*

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1. INTRODUCTION

One of the most common technologies for bridge construction in difficult terrain conditions is the cantilever construction technology which is implemented in two ways: monolithic, also called "cantilever concrete method" and assembling – "cantilever assembly method" [1], [2].

Throughout the entire construction period, construction and assembly works are accompanied by precise geodetic measurements in order to perform an executive survey of the already constructed parts of the bridge and setting out works during the construction of its subsequent parts. The scarce literature on this issue [3], [4] mentions that measurements are carried out with a total station, and for each stage of the implementation of the cantilevers, depending on the geometry of the project, relevant preparatory calculations are carried out – mainly coordinate transformations and setting out data.

Given the exceptional importance of geodetic measurements in cantilever bridge construction, reliable control of the computational work and geodetic setting out for spatial orientation (so-called navigation) of the cantilevers must be carried out at each stage of implementation. According to the author, this implies the development of a geodetic control system, including at least a high-precision geodetic device for defining spatial coordinates, a portable field computer with special software for calculating the setting out data and a means of communication between them.

This idea is the basis of a research project developed at the University of Architecture, Civil Engineering and Geodesy aiming to create a working model of a geodetic control system for building of bridge superstructure construction using the cantilever method. The main idea, the functional block diagram, the equipment involved and the functional model of the system are discussed in this article.

2. PROJECT FOR A GEODETIC CONTROL SYSTEM IN BUILDING OF BRIDGE SUPERSTRUCTURE CONSTRUCTIONS USING THE CANTILEVER CONCRETE AND ASSEMBLY METHOD

The project was developed under a contract with the Center for Scientific Research and Design at University of Architecture, Civil Engineering and Geodesy aiming to create a working model of a geodetic control system in building of bridge superstructure constructions using the cantilever concrete or assembly method. The project was realized by a design team including the author.

2.1. Purpose of the geodetic control system:

The geodetic control system is designed to provide:

- fast and reliable preparation of the necessary data for spatial orientation of the cantilever concrete facility or correction of the assembled cantilever segment at each stage of construction in compliance with the facility design project.
- providing the necessary graphic and textual information to the operator of the cantilever concrete facility or the assembly crane;
- reliable two-sided control of the location of the cantilever concrete facility;
- two-sided connection with the facility designer via Internet;
- automated preparation of executive documentation for each stage of construction.

2.2. Necessary prerequisites for the functioning of the geodetic control system:

- A laid, measured and adjusted bridge geodetic network, providing the necessary accuracy in plan and height for setting out and control when building bridges using monolithic method and/or assembly method of supporting structures.
- Results (files) from the dimensioning of the bridge's supporting structure with special software – SOFISTIK [5] and the elements defining the local coordinate system of the bridge used in the software.
- Construction working schemes (files) of the abutments, pillars and supporting structure; longitudinal profile of the linear object (road, railway line, etc.); coordinates of the peg pints of the axis of the linear object within the scope of the bridge, in a geodetic coordinate system.
- Results of the executive measurements of the constructed elements of the substructure: abutments and pillars.

The following presentation covers a variant of the geodetic control system using a robotic total station as a measuring system module.

2.3. Functional block diagram of the geodetic control system

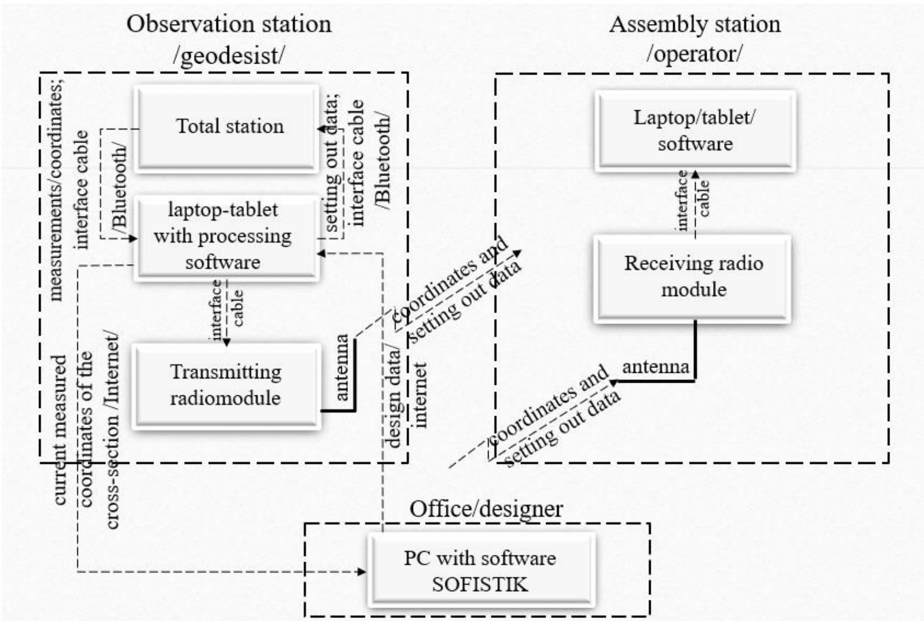

Figure 1. Functional block diagram of the geodetic control system

2.4. Equipment

The system equipment has been determined taking into account the geodetic tools, special software and computing devices available at the University - UACEG.

The requirement to provide graphic and textual information to the operator of the cantilever concrete facility or the assembly crane to support their work in locating the facility or the assembled segments implies the presence of two system modules: observation and user.

2.4.1. Observation module (observation station)

The module includes the following components (Figure 2):

- Total station (preferably robotic or at least with the ability to measure distances up to 150-200 m without a prism) with appropriate angular and longitudinal accuracy and interface - RS232/USB, Wi-Fi.
- 10.4" laptop-tablet controller Panasonic CF-19 convertible (outdoor use-sunlight readable, 3G-module), attached to the tripod of the total station; operating system – Windows 7 Pro.
- Transmitting radio module 2.4 GHz with directed antenna (600/750) connected to the control laptop with an interface cable.
- Special software for processing the measured information, preparation of setting out data, visualization, communication and data transfer from and towards the total station to the tablet of the assembly station via radio interface and towards the designer's computer via Internet.

Figure 2. Oservation station

In this particular case, the use of a robotic total station is suggested Topcon IS 203 [6], [7] which can measure distances up to 250 m without a prism with an accuracy of 3 mm and angular accuracy on both circles 3″; interface – USB, Bluetooth, Wi-Fi; operational system – Windows CE NET 4.2.

2.4.2. Assembly module (assembly station – Figure 3)

- 10.4" laptop-tablet Asus 104tm, operational system Windows 7;
- Receiving radio module 2.4 GHz with non - directed antenna;
- Special software for receiving and visualizing setting out data from the observation module.

Figure 3. Assembly station

2.4.3. Office/Designer

- Personal computer with installed SOFISTIK software and Internet connection.

2.5. Model of functioning of the geodetic control system

The functional model presented here was developed based on the general technological plan for the implementation of the supporting structure and the corresponding stages of the computational model used in SOFISTIK.

2.5.1. Computational model

The geometric axis of the bridge's supporting structure is part of the axis of the linear object (road, railway line) which is defined by its main and detailed points in a geodetic coordinate system. In SOFISTIK the axis of the facility is represented by a series of points (nodes) but in a local coordinate system for the facility OXYZ (Figure 4).

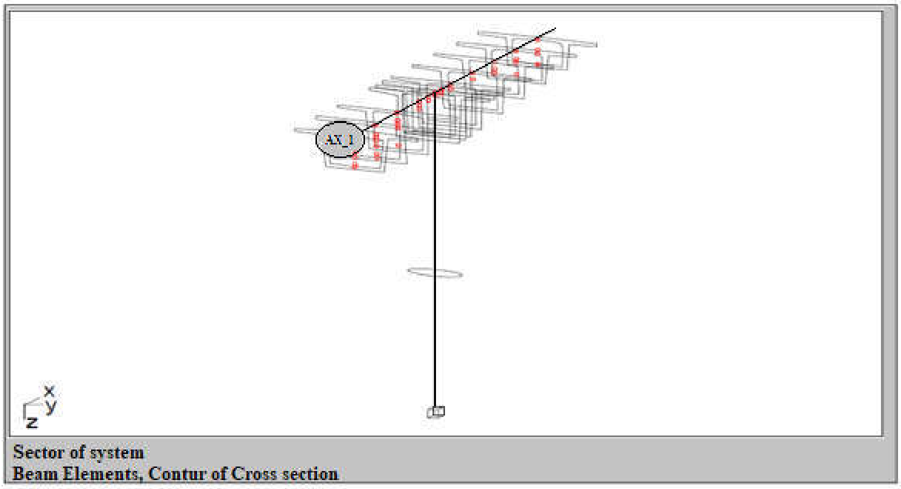

Figure 4. Axis of the facility

The beginning of the coordinate system can be chosen at any node but it is preferable to coincide with a peg pint of a straight section before the initial abutment or in the center of the abutment itself. The direction of the X axis is in the direction of the axis of the facility, if it is straight and, respectively, in the direction of the common tangent, if it is curved. The directions of Y and Z axes are visible in the figure above.

Each pair of consecutive cross-sections closes the so-called “beam end element” which physically represents a construction element (block or segment) of the cantilever. From a computational point of view, the element is defined by two consecutive cross-sections “attached” to the axis of the facility with the center points (Figure 5).

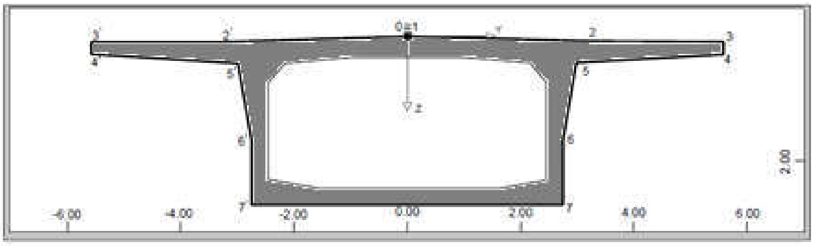

Figure 5. Cross-section

The design of the structure is carried out for each node, in successive steps, called loadcases, corresponding to the stages of construction.

As a result of the calculation of the construction with SOFISTIK software, the following files are obtained:

- A file containing the three-dimensional coordinates of all nodes of the bridge axis in the local coordinate system of the facility.

Nodal Coordinates and Supports			
Number	X[m]	Y[m]	Z[m]
101	0.000	0.000	0.000
102	0.350	0.000	-0.021
103	1.350	0.000	-0.081
104	2.550	0.000	-0.153

- File containing a list of all loadcases from the calculation of the bridge support structure.

Loadcasenumber	Title
4001	Piers
4005	Creep 50 days
4010	Pier table

- A file containing the coordinates of the contour points of each section but in a local coordinate system for the section itself, starting at the corresponding node (Figure 4), arranged in ascending order by cross-section type number.

node /	cross-sec. /	y;z т.1	y;z т.2	y;z т.3	y;z т.4	y;z т.5	y;z т.6	y;z т.7
101 /	5 /	0.000;0.000	3.500;0.000	5.580;0.000	5.580;0.300	3.000;0.300	2.750;0.300	0.000;0.300
102 /	5 /	0.000;0.000	3.500;0.000	5.580;0.000	5.580;0.300	3.000;0.300	2.750;0.300	0.000;0.300
102 /	3 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
103 /	3 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690

- Files containing the values of the translations of the central point of each section (pt. O – Figure 5) and the rotations of its axes, for each loadcase, relative to the local coordinate bridge system.

Nodal Displacements
Loadcase 4001: Piers

Node. Nr	UX [mm]	UY [mm]	UZ [mm]	PHIX [mrad]	PHIY [mrad]	PHIZ [mrad]
1138	21.902	0.0000	-3.9790	0.0000	0.1108	0.0000
1165	-18.188	0.0000	-4.2420	0.0000	-0.3585	0.0000
2138	0.000	0.0000	0.0000	0.0000	0.0000	0.0000
2165	0.000	0.0000	0.0000	0.0000	0.0000	0.0000

2.5.2. Preparation of the geodetic control system

1) The preparation of the geodetic control system for operation on a specific site (bridge) begins with the creation of a project in a special software[2] for management and procession of measurement data installed on the observation module.
2) The project directory gets the files from the constructional decision of the bridge with SOFISTIK software and a file containing the coordinates of the points from the bridge setting out network.
3) At the site, the operator centers the total station over the point selected as the observation station, sets the control laptop on the device tripod, connects the transmitting radio module to the antenna and the laptop, turns on the control laptop and starts the control software. Similarly, in the cantilever concrete facility, the components of the assembly module are connected.
4) Transfer of the file with the coordinates of the points from the bridge network from the control laptop to the total station memory.
5) Performing the necessary measurements towards points of the bridge network in order to initially establish or to control the coordinates of the observation station with the option „Free Station".

2.5.3. Working with the geodetic control system during the cantilever construction

It is assumed that over-the-pillar block has been built and the cantilever concrete facility has been assembled to build the first block of the cantilever but it is not located according to the design, but only approximately.

Work with the geodetic control system during the cantilever construction is as follows:

1) determination of the three-dimensional geodetic coordinates of the points from the outer contour of the cross-section (front) of the formwork
2) comparison of the determined coordinates with the design coordinates
3) calculation of the necessary corrections along the three coordinate axes
4) adjustments in the orientation of the installation so that its front takes the design position.

All these operations are described in detail in the author's dissertation [8].

The described functional model essentially includes the generalized algorithm for processing information at each stage of the construction of the supporting structure.

2.5.4. Information processing algorithm

It processes the output data and geodetic measurements in order to provide the construction process with the necessary setting out data and performing geodetic control at each stage of the construction and installation works.

[2] The software was developed by a professional programmer (a member of the design team) in the algorithmic language C++ under Windows 7 Pro operating system. The program is designed for management and procession of measured information, preparation of setting out data, visualization, communication and data transfer from and towards the total station, to the tablet of the assembly station via radio interface and towards the designer's computer via Internet.

- **Registering output information:**
  - Entering the coordinates of the bridge setting out network – text file **Network.kor**.

For example: Coordinate system: 1970, Height system: Baltic.

File structure:

Site name, Coordinate system, Height system

№ X, m Y, m H, m mx my m_H

....

- Registering the necessary text files from the bridge dimensioning with SOFISTIK:

File with loadcases in facility calculation **Loadcases.txt**.

File structure:

Loadcasenumber Title - execution step

4001 Piers

4005 Creep 50 days

4010 Pier table

4011 Prestress

4015 Creep 50 days

4020 dead load CS #20

4030 dead load CS #30 20

4031 Prestress CS #31

....

File with nodes coordinates (the points from the bridge axis) **Nodes.kor**.

Coordinate system – Spatial, local to the facility, set in SOFISTIK.

File structure:

Table 1

Nodal Coordinates and Supports

Number	X[m]	Y[m]	Z[m]
101	0.000	0.000	0.000
102	0.350	0.000	-0.021
103	1.350	0.000	-0.081
104	2.550	0.000	-0.153
105	3.150	0.000	-0.189
106	7.250	0.000	-0.435
107	11.350	0.000	-0.681
108	15.450	0.000	-0.927
109	19.550	0.000	-1.173
110	23.650	0.000	-1.419
111	27.750	0.000	-1.665
112	31.850	0.000	-1.911
113	35.950	0.000	-2.157
114	40.050	0.000	-2.403
115	44.150	0.000	-2.649
116	48.250	0.000	-2.895
117	52.350	0.000	-3.141
118	54.150	0.000	-3.249
119	55.350	0.000	-3.321
120	56.550	0.000	-3.393

File with translations and rotations in the nodes from the facility axis for all loadcases **displacements.txt.**

Coordinate system – local to each node

File structure:

Table 2

```
Nodal Displacements
Loadcase 4001:   Piers
Node.          UX          UY          UZ        PHIX        PHIY        PHIZ
      Nr     [mm]        [mm]        [mm]     [mrad]      [mrad]      [mrad]
    1138   21.902      0.0000     -3.9790     0.0000      0.1108      0.0000
    1165  -18.188      0.0000     -4.2420     0.0000     -0.3585      0.0000
    2138    0.000      0.0000      0.0000     0.0000      0.0000      0.0000
    2165    0.000      0.0000      0.0000     0.0000      0.0000      0.0000

Nodal Displacements
Loadcase 4005:   Creep 50 days
Node.          UX          UY          UZ        PHIX        PHIY        PHIZ
      Nr     [mm]        [mm]        [mm]     [mrad]      [mrad]      [mrad]
    1138   21.902      0.0000     -2.6914     0.0000      0.1108      0.0000
    1165  -18.188      0.0000     -2.9544     0.0000     -0.3585      0.0000
    2138    0.000      0.0000      0.0000     0.0000      0.0000      0.0000
    2165    0.000      0.0000      0.0000     0.0000      0.0000      0.0000
```

Cross-section schemes files in format dxf.
File name: **Node №.dxf.**
A **file describing the contour of the sections** with a series of points with coordinates Node №*txt (half of the cross section is given, see the following scheme).

Coordinate system: local in the cross-section plane
File structure

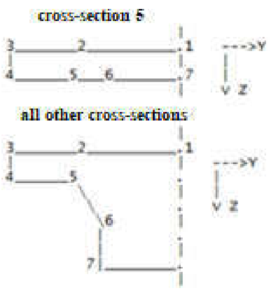

Figure 6. Cross-section

Table 3

node /	cross-sec. /	y;z т.1	y;z т.2	y;z т.3	y;z т.4	y;z т.5	y;z т.6	y;z т.7
101 /	5 /	0.000;0.000	3.500;0.000	5.580;0.000	5.580;0.300	3.000;0.300	2.750;0.300	0.000;0.300
102 /	5 /	0.000;0.000	3.500;0.000	5.580;0.000	5.580;0.300	3.000;0.300	2.750;0.300	0.000;0.300
102 /	3 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
103 /	3 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
104 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
105 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
106 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
107 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
108 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
109 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
110 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
111 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
112 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
113 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
114 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
115 /	1 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690
116 /	2 /	0.000;0.000	3.500;0.090	5.580;0.090	5.580;0.290	3.000;0.430	2.750;1.690	2.750;2.690

- **Pre-processing of the output information:**
  - ➢ Calculating the coordinates of the right part of the cross-sections from a file **Node №*txt** in the same coordinate system, recording the coordinates for each section in a separate file **Sec№LS.txt** with structure:

Node № Cross-section№, date
Point № У, m Z, m

1	0.000	0.000
2	3.500	0.000
....		
13	-5.580	0.000

- Transforming the coordinates from file Sec№LS.txt into the bridge coordinate system (**B**ridge **S**ystem), record in file **Sec№BS.txt.**
- Transforming coordinates from file **Sec№BS.txt** into the geodetic coordinate system, record in file **Sec№GS.txt**.

- **Ongoing procession of the cantilever construction**

  - **Beginning of a cycle**
  - Entering the cross-section (node) number **SecNumber** and **Loadcase** number;
  - File transfer **Sec№GS-date.kpt** from the total station to the control laptop; registering the file into the processing software;
  - Coordinate transformation from file **Sec№GS-date.kpt** in the local coordinate system of the cross-section; record in file **Sec№LS-date.kpt**;
  - Recalculation of the design coordinates of the cross-section (file **Sec№LS.txt**) with the translations and rotations of the cross-section after the execution of the corresponding stage of the cantilever construction (file **displacements.txt**);
  - Calculation of corrections (translations) **dy, dz** which must be used to adjust the front of the cantilever concrete facility so that it takes its design position. Used files coordinates Sec№LS.txt and **Sec№LS-date.kpt**;
  - Drawing schemes of the design and actual cross-section, displaying the values of the corrections **dy, dz** and their directions;
  - Sending data to the assembly module via radio interface;
  - File transfer **Sec№GS.txt** in the total station. This file will be used by the total station operator for setting out and control;
  - File transfer **Sec№GS-date.kpt** from the front control measurement in the control laptop and sending to the designer's office via Internet;
  - Entering the next loadcase and repeating the same operations;
  - **End of cycle** (after depletion of all loadcases for the given cross-section);
  - **Beginning of a new cycle** – entering the next cross-section and loadcase, etc.

The accuracy in building superstructure bridge constructions using the cantilever concrete or assembly method is a subject of another article by the author [9].

CONCLUSION

The developed system for geodetic control in cantilever bridge construction significantly improves the reliability and efficacy of construction processes by providing accurate and fast setting out data and automated documentation. The current model of the system operates with the help of a robotic station Topcon IS 203, laptop-tablets Panasonic CF 19 and Asus 104TM as well as a set of radiomodules with range of about 200 m which allow integration of different total station models, including those without Bluetooth and Wi-Fi. The ability to use total stations with advanced communication options (like Long Range Wi-Fi) is also provided which increases the flexibility of the system. Prospects for improving the system include the implementation of modern technologies and software platforms to increase its functionality and convenience which will contribute to even greater accuracy and efficacy when building bridge constructions.

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