Special Topographical Assistance to the Raising of the Cernavoda Bridge over the Danube – Black Sea Channel

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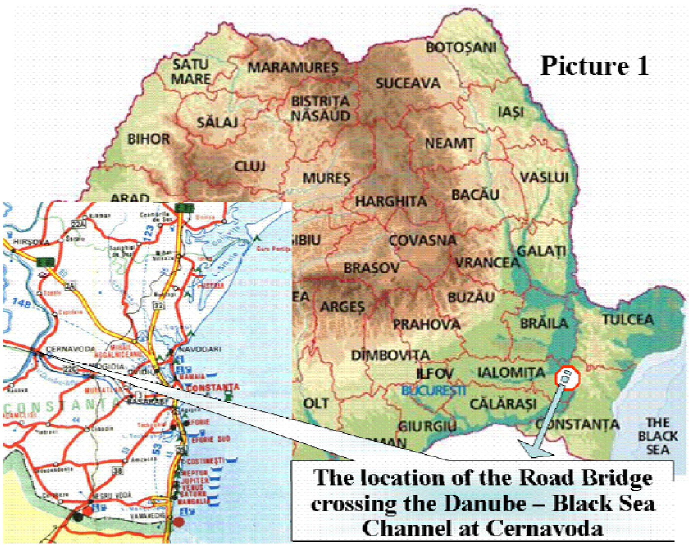
Key words: reference system, high precision geodetic network, standard deviation, technical assistance, trajectory high precision stakeout, monitoring a moving object, high accuracy designed level supervision, total station, automatic level.

SUMMARY

The new bridge crossing the Danube – Black Sea Channel at Cernavoda provides the best connection between the city and the Railway Station of Cernavoda town. The bridge construction was imposed also by the requirements for Nuclear Power Plant operation in service from 1995 and its location is not far away from the town (Picture 1).

The functional considerations that had the greatest influence on conceptual choice of the bridge form and type of the structure were: the topography and geology of the site, the clearance requirements for navigations and the avoidance of ships impact to bridge substructure.



Picture 1

To illustrate the importance of the special topographical services during the final erection procedure of the main bridge structure is necessary to underline some technical characteristics. The bridge consists of three structures with a total length of 523.5 m.

On each side of the main structure there is a continuous composite structure for the access viaducts, on the right side two spans (total length 88 m) and on the left side seven spans (total length 263 m). The main span of 171.0 m, over the Channel, is covered by a *Nielsen* arch steel structure with an orthotropic deck.

For the arch structure, a combination of some methods of erection was used:
Phase 1- assembling the structure on a platform carried out on the right bank, near the final location;

Phase 2 - sliding on a temporary sliding way by pivoting about a vertical axis and loading of the left end of the structure on a barge;
Phase 3 - shipping to the left bank; reaching the designed alignment;
Phase 4 - launching to the final position;
Phase 5 - lifting to the designed level.

During the erection procedure the following conditions were imposed:
- the structure must be supported only on the bearing location;
- the right end of the structure must be permanent bearing on the Channel bank;
- the closing of the Channel navigation must be minimum.

This paper presents some aspects of the position control and special engineering survey services during the main bridge structure erection to the final position and to the designed level.

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1. REQUESTED MEASUREMENTS

The erection methods of the main arch structure presented in the Summary, requested special engineering survey services, including design, measurement procedures and field activities for each erection phase, necessary to the final positioning of the main bridge:

Phase 1:

- for the determination of the metallic structure geometry, in the first stage, were established the coordinates of about 180 characteristic points, marked on the bridge, with a standard deviation of ± 3 mm, in the reference system of the bridge. Moreover, these measurements had the purpose of verifying the evolution of the superstructure during the phase of putting the crossed hangers under tension. The same points were determinate and the 3D coordinates were compare with the designed ones both in the initial cycle and in the other five cycles carried out after the important stages of crossed hanger tensioning.

Phase 2:

- the high precision stakeout of the trajectory on the temporary slide way according with the designed coordinate;
- technical assistance required of a correct and precise pivoting and positioning of the main bridge on a temporary metallic foundation;

Phase 3:

- technical assistance and coordination each sequences of the rotation by shipping to the left bank of whole ensemble consist of the main bridge structure and the barge, that means by topographical point of view monitoring a moving object on a designed trajectory;
- reaching the designed alignment of whole ensemble between the two wall type piers;

Phase 4:

- technical assistance for each sequences of launching to the final position, that means “keeping” of whole ensemble on the designed alignment and monitoring the designed level;

Phase 5:

- supervision and specific high accuracy works required for the lifting to the designed level.

2. ENGINEERING SURVEY PROCEDURES

2.1 High Precision Geodetic Network

On the whole construction of bridges, metallic bridges are standing out both by the varied design solutions and by the special needs for precision in execution and fitting. For the integration within the general limits of errors a special attention should be given to establishing the precisions of measurement processes in all phases of construction achievement.

For all complexes phases used to the erection of the main structure it was necessary to achieve a spatial geodetic network of high precision and from its points the possibility of taking precise measurements in horizontal and vertical planes should be available.

The positions of the projected network points were chosen in such a way that all the interested points, marked on both sides of the main bridge, could be seen, as much as possible, under favourable intersection angles and the lines of sight. It was also necessary to include in this network points which mark the designed alignment of the main bridge, out of the influence zone of the construction works. Field marking of projected network points was done with pilasters equipped with forced centring devices (especially for those from the right bank) and with concrete pillars for the rest of the points.

In order to increase the precision of the altimetry position of network points, these were included in a high precision geometric levelling network.

A unique height system for the points of the entire network was used. Transmitting the heights over the channel, operation extremely difficult considering the breadth of the channel and the precision that must have been ensured, was completed with the precise classical geometric levelling instrument and with invar rods. The observations were accomplished according to a strict symmetric program, with a view to decrease to a maximum the influences of Earth curvature, atmospheric refraction, instrumental errors and all inevitable errors that interfere at measurement.

2.2 Performing the Measurements

The measurements required by the first and the second phase are accomplished during the execution of the main bridge on the right bank of the Channel, near the final location. First phase was a very complex process, carried on for a long time and its final aim was the determination and evolution of the metallic structure geometry during the execution, especially during the phases of putting the crossed hangers under tension. The second phase has included the high precision stakeout of the trajectory on the temporary slide way according with the designed coordinate and, finally, the technical assistance required for a correct and precise pivoting and positioning of the main bridge on a temporary metallic foundation.

The measurements required by the phase 5 are accomplished during the lifting of the main bridge, by means of some special *Freyssinet type* devices, to the designed level. From topographical point of view it was a routine operation, accomplished step by step, in accordance with the designed schedule of events.

The main subject of this paper is the engineering survey measurements accomplished during the *Phase 3* and *4* procedures. That means topographical assistance for each sequences of the rotation by shipping to the left bank of whole ensemble formatted by the main bridge structure and the barge and for each sequences of launching the main bridge to the final position.

2.3 Required conditions

From many reasons, *Phase 3* and *4* were the most spectacular operations and the following conditions have been imposed:

- favorable meteorological conditions;
- water optimal level in Channel;
- water optimal level on the designed trajectory according with the barge clearance diagram (it was necessary to drag before the Channel on the entire designed trajectory);
- a very short time for operations (12 hours, on optimal conditions), because the closing of the Channel navigation must be minimum;
- the structure must be supported only on the bearing location;
- the right end of the structure must be permanent bearing on the Channel bank;
- entire operation complexity;
- entire operation security;

All these conditions requested a very high accuracy for each stage and for these reasons the *D-Day* of the operations was chosen.

The schedule of events for *D-Day* was performed by the general coordinator of all operations and this must be respected by all companies which are involved. This schedule included all main procedures, time and details (Table 1):

Table 1

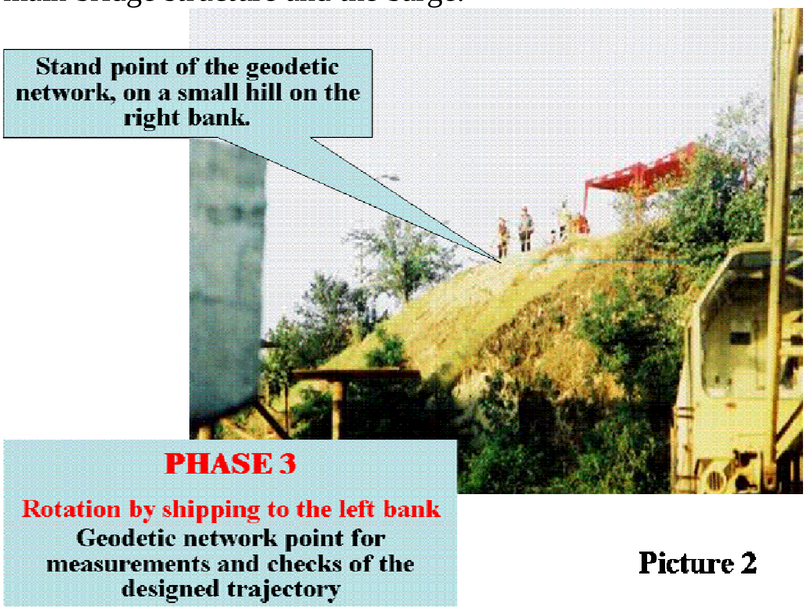
Time	Procedures to perform
5^{30}	**THE ESTABLISHMENT OF THE ROTATION REFERENCE**: - define on field of the reference plane and level - check the concordance with the ICEPRONAV reference level - check the concordance with Freyssinet reference level
5^{45}	**START ORDER OF THE WHOLE ENSEMBLE (MAIN BRIDGE AND BARGE)**
6^{00}	**ROTATION BY SHIPPING (72^0 - 214.885 m)**
8^{00}	THE FIRST CHANGE OF THE FREYSSINET CABLES (24^0 - 71.628 m)
10^{00}	THE SECOND CHANGE OF THE FREYSSINET CABLES (48^0 - 143.256 m)
13^{00}	THE THIRD CHANGE OF THE FREYSSINET CABLES (72^0 - 214.885 m)
13^{30}	**CHANGE THE PIVOT SYSTEM IN SLEDGE SYSTEM**
16^{30}	**THE ESTABLISHMENT OF THE LAUNCHING REFERENCE – LAUNCHING I** - define the designed alignment of the bridge, between the two wall type piers - define the launching reference level
16^{40}	**LAUNCHING I – BRIDGE ON THE BARGE**

	- keep the whole ensemble on the designed alignment - watching at the designed level
17[20]	**FIXING THE END OF BEAMS IN THE NICHES OF THE LEFT BANK PIER**
18[00]	**THE ESTABLISHMENT OF THE LAUNCHING REFERENCE – LAUNCHING II**
20[00]	**LAUNCHING II – BRIDGE ON THE BEAMS ES2 AND ES3 (☞ 22.42 m)** - keep the whole ensemble on the designed alignment - watching at the designed level
22[00]	**TAKING OVER THE MAIN BRIDGE IN THE RAISING BELTS**
23[30]	**END PROGRAM**

2.4 Performing the Measurements for the Rotation by Shipping

2.4.1 Monitoring the designed trajectory

For this aim, it was required to provide technical assistance and coordination of each sequences of the rotation by shipping to the left bank of whole ensemble formatted by the main bridge structure and the barge.



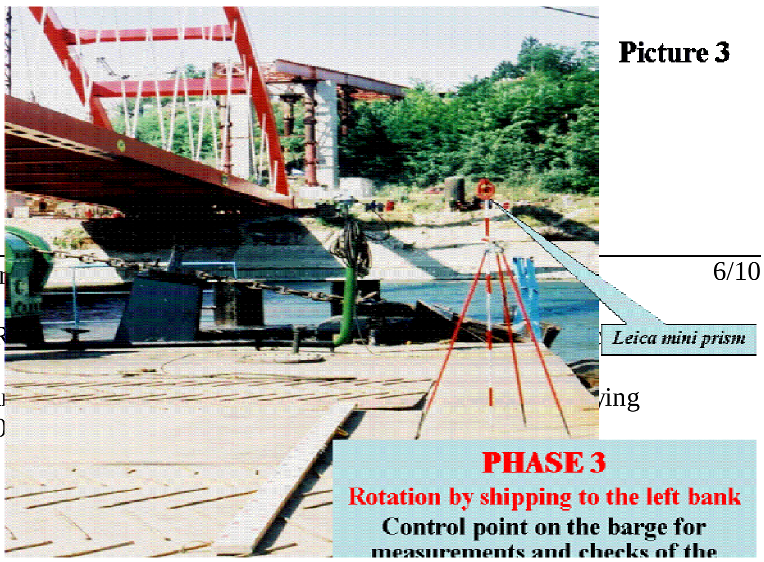
Picture 2

In fact, that means for us to design and achieve a topographical procedure for monitoring a moving object on a designed trajectory.

The whole ensemble must pivot about a vertical axis (fixed point was a very complex pivot-device, on the right bank), and must have a circular trajectory. Our mission was "to keep" the whole ensemble on this circular designed trajectory.

Schedule of the engineering survey field works at *D-Day*:

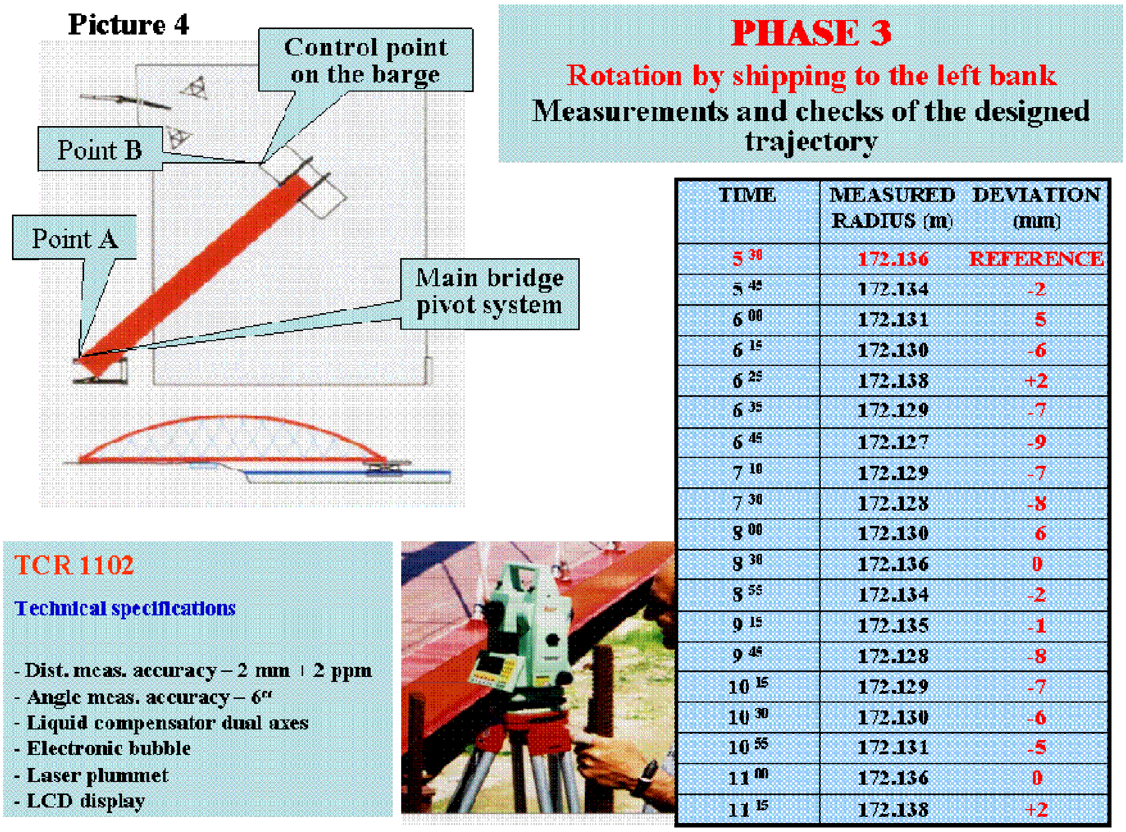
- a simulation of a barge (only) on the designed trajectory was performed a few days before;
- it was chosen a stand point from the geodetic network, on a small hill on the right bank which offered the optimal conditions to observe all the movement of the ensemble on its trajectory (Picture 2);
- on the right end of the main bridge a point was marked to define the vertical axis of the pivoting system (let's name it **A**);



Picture 3

- on the barge was marked a point (let's name it B) and a *Leica mini prism* was installed (Picture 3);
- before the rotation start time the AB distance was measured and a reference value was established. This distance became the circular trajectory radius and must be the same on all the rotation route;
- any significant deviation from this reference value must be an alarm signal and all process must be stopped and the ensemble main bridge – barge must be put again on the designed trajectory;
- at each 15 minutes, the coordinator of all operations must receive the technical report about the trajectory deviations (Picture 4);

Picture 4



TIME	MEASURED RADIUS (m)	DEVIATION (mm)
5^{30}	172.136	REFERENCE
5^{45}	172.134	-2
6^{00}	172.131	5
6^{15}	172.130	-6
6^{25}	172.138	+2
6^{35}	172.129	-7
6^{45}	172.127	-9
7^{10}	172.129	-7
7^{30}	172.128	-8
8^{00}	172.130	6
8^{30}	172.136	0
8^{55}	172.134	-2
9^{15}	172.135	-1
9^{45}	172.128	-8
10^{15}	172.129	-7
10^{30}	172.130	-6
10^{55}	172.131	-5
11^{00}	172.136	0
11^{15}	172.138	+2

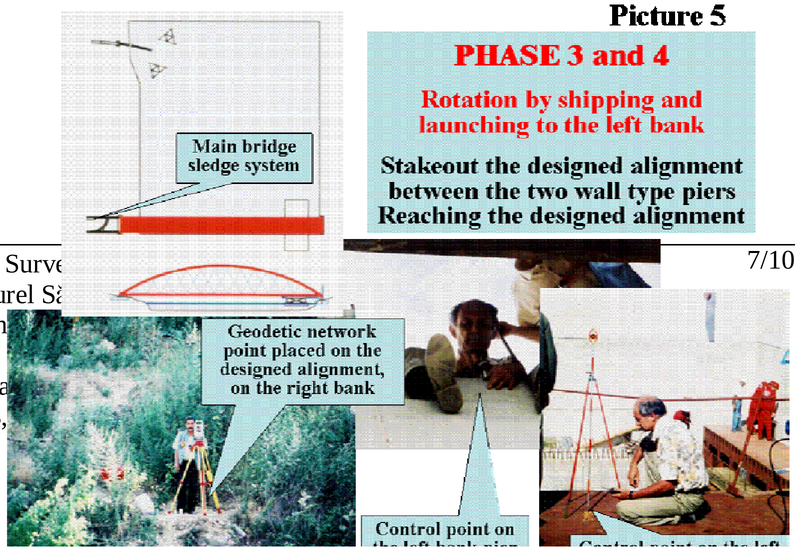
- all measurements were performed with *Leica* TCR 1102 and its special function *Tie Distance* was used;

2.4.2 Achievement of the designed alignment

To define the designed alignment of the bridge between the two *wall type* piers we used a network point placed on the right bank, a longitudinal axis point marked at the left end of the main bridge and an axis point of the left bank pier (Picture 5). '

The right end of the main bridge was placed on the designed alignment at the

Picture 5



moment of change the pivot system in sledge system.

The change of place was made by simultaneous push from the right bank with two special devices.

Our mission was monitoring the displacement (the launching) of the main bridge to the left bank pier on the designed alignment and *to keep* the whole ensemble on this alignment. Any deviation from this designed route can compromise all operation. All this operations were also performed with *Leica* TCR 1102.

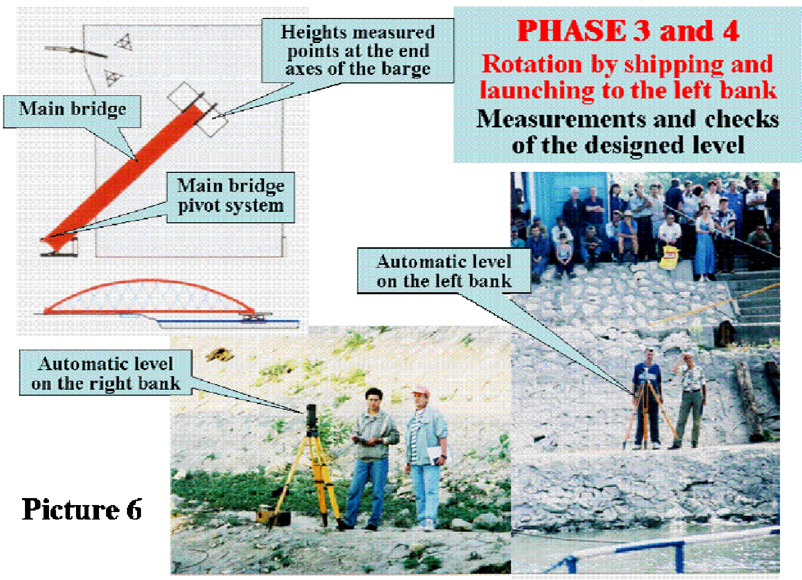
2.4.3 Monitoring the designed level

It was the most difficult and the most important to provide the designed level of the barge, because any deviation can lead to the interruption of operations or to serious damages.
For this mission there were three systems working in the same time and technical reports about the ensemble main bridge – barge position provided.

The first one was an electronic system for monitoring small inclinations, belongs to *Freyssinet* (French company), placed on the left end of the main bridge.
The second one was a dual axes plate level, with pendulum, belongs to ICEPRONAV (Romanian company), placed on the barge control cabin.

The third level monitoring system was proposed by Faculty of Geodesy Bucharest. The solution consist in double and simultaneous level measurements from both banks towards four characteristic points placed at the end of the main axes of the barge.

Before the start time of entire operation were established the reference height values for each of these points, from network points placed on the two banks.



Picture 6

Our mission was “to keep” the height values of these points on all route of the whole ensemble until the end of the rotation operations (Picture 6).

Any barge small deviations from the designed level can be compensated and the clearance diagram to the main axes directions (longitudinal and transversal) can be performed by its own high debit pumps.

Any abrupt deviations from these values, over the ± 100 mm range should be an alarm signal and all operations should be stopped.

At each 15 minutes, the coordinator of all operations must receive the technical reports about the level measurements and the deviation values.

Starting to the launching operation of the main bridge and up to the final position on the left bank pier the same topographical procedure was used.

All level measurements were performed with two high performance automatic levels, high magnification and accuracy.

The technical reports of other two systems of level monitoring were comparables with the double and simultaneous level measurements and all these three systems led to the accuracy and security of the rotating-launching operation of the main bridge.

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BIOGRAPHICAL NOTES

Johan NEUNER, Technical University of Civil Engineering Bucharest - Faculty of Geodesy, Professor, Doctor Engineer in Geodesy, Dean of the Faculty, *professional experience* in Education and Training of students for Surveying and Mapping, Engineering Survey and GPS application, *membership* of Union of Romanian Geodesy, *experience* in Engineering Survey, Deformations measurements, *special experience* in Geodetic GPS application, *various publications* in national and international workshops, congresses and scientific magazines.

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