Multibeam and sidescan sonar application for determining the position and shape of the remains of Hadrian bridge on Drava river

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Key words: Hadrian bridge, hydrography, multibeam, side-scan sonar, Drava river

SUMMARY

During underwater archeological research on the Drava river in Osijek, the remains of a Roman stone bridge were documented. It was found that it were the remains of Hadrian's bridge. Hadrian was a Roman emperor in the period from 117 to 138 AD. The remains of a stone bridge have been known for many years and first records of them date from year 1777. In the year 1938 started the removal of the remains of the bridge due to their interference with the Drava river waterway. Later in the fall of year 1985 further removal of the pillars of the bridge was conducted, unfortunately with dynamite and excavators, and after mining, stone remains were removed by excavator to the river barge. Among the remains stone reliefs depicting Satire and Menada, the top railings of the bridge endings, profiled blocks, stone altar dedicated to Jupiter, and blocks with the hole for the lead-iron clamps were found. Until year 2008 when valuable statue of Jupiter was found in the Drava river near the site of Hadrian bridge, no research activities were conducted around the bridge. Also precise location of the bridge was unknown due to the speed of the river Drava and poor visibility due to large amounts of mud in the river (visibility 30cm). The paper shows the continuation of research, where for the purpose of getting the complete image of the remains of columns and their spacing, precise bathymetric map was created by means of multibeam echosounder and side scan sonar measurements (digital relief of the bottom). Also, a problem was the identification and re-position of the bridge remains since the precise position has never been documented, and aggravating factors were large deposits of the river Drava which very quickly covered the dynamited remains of the bridge. After creating these maps, information about the distance between the columns that are not equal to the pillars in the middle of the river and one on the side were obtained. These data should contribute to clearer image of the layout and structure of the bridge.

SUMMARY (optional summary in one other language in addition to English, e.g. your own language)

Tijekom podvodnog arheološkog istraživanja na rijeci Dravi kod Osijeka dokumentirani su ostaci kamenog rimskog mosta. Utvrđeno je da su to ostaci Hadrijanovog mosta. Hadrian je bio rimski car u periodu od 117 do 138 godine. Sami ostaci kamenog mosta poznati su već dugi niz godina, prvi zapisi spominju ih već 1777. godine. Tijekom 1938. godine zbog stalne smetnje plovnom putu rijeke Drave pristupilo se njihovom uklanjanju. Kasnije, u jesen 1985. godine pristupilo se daljnjem uklanjanju stupova mosta, nažalost miniranjem i buldožerima, međutim tada su nakon miniranja bagerom vađeni kameni ostaci na riječni šlep. Među

kamenim ostacima nalaze se reljefi s prikazima Satira i Menada, gornji završetci ograde mosta, profilirani kameni blokovi, kameni žrtvenik posvećen Jupiteru te kameni blokovi s rupom za olovno –željeznu spojnicu. Do 2008. godine kada je u rijeci Dravi u blizini lokacije Hadrijanovog mosta pronađena vrijedna statua Jupitera, nisu provođena istraživanja na mostu, a i točna lokacija mosta zbog brzine rijeke Drave i velike zamuljenosti (vidljivost 30cm) bila je nepoznata. U radu se prikazuje nastavak istraživanja gdje je za potpunu sliku ostataka stupova i njihovog razmaka multibeam echosounderom te side scan sonarom izrađena precizna batimetrijska karta dna (digitalni reljef dna). Također problem je predstavljala i ponovna identifikacija položaja mosta budući precizna pozicija nikada nije dokumentirana, a otežavajući faktor predstavljaju i veliki nanosi rijeke Drave koji minirane ostatke stupišta mosta vrlo brzo prekriju. Nakon izrade te karte dobiveni su podatci o udaljenosti između stupova koje nisu jednake za stupove na sredini rijeke i one bočne. Ti podaci trebali bi doprinijeti jasnijoj slici o izgledu i građi mosta.

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1. INTRODUCTION

During underwater archeological research on the Drava river in Osijek, the remains of a Roman stone bridge were documented. It was found that it were the remains of Hadrian's bridge. Hadrian was a Roman emperor in the period from 117 to 138 AD. The remains of a stone bridge have been known for many years and first records of them date from year 1777.
Then the Franciscan monks floating down the river saw six stone pillars in the water. Since then the remains were mentioned several times in historical records. In the year 1938 started the removal of the remains of the bridge due to their interference with the Drava river waterway. For their removal boat which had a heavy mallet installed on it was used. Remnants of the stone pillars were crushed with that mallet. Thereafter until 1983 the remains of the bridge did not wake greater interest. Later in the fall of year 1985 further removal of the pillars of the bridge was conducted, unfortunately with dynamite and excavators, and after mining, stone remains were removed by excavator to the river barge. Among the remains stone relief depicting Satire and Menada, the top railings of the bridge endings, profiled blocks, stone altar dedicated to Jupiter, and blocks with the hole for the lead-iron clamps were found and placed in the Museum of Slavonia. When removing, the excavator also ripped few oak pylons with iron fittings at the top. In mining and dredging logs, four pillars are listed with an altitude difference of 7 meters between the highest pillar residue and the river bottom. It is a great pity that archaeological excavation of the remains hasn't been done that time. The highest preserved pillars can be found on the left bank of the river and have the height of about 2.5 meters. The remains of the pillars resemble a meshed pile of processed and crushed stones with smaller wooden pylons and for now it is not possible to see the processed stone which is in its original position. It must be emphasized that on the location conditions for diving are extremely unfavorable, the visibility does not exceed 30 cm due to large amounts of mud in the river, and the current does not allow swimming upstream. (Gardaš 2001), (Gardaš 2002), (Pinterović 1978)
The paper shows the continuation of research, where for the purpose of getting the complete image of the remains of columns and their spacing, precise bathymetric map needed to be created by means of multibeam echosounder measurements (digital relief of the bottom).
Also, a problem was the identification and re-position of the bridge remains since the precise position has never been documented, and aggravating factors were large deposits of the river Drava which very quickly covered the dynamited remains of the bridge. After creating these maps, information about the distance between the columns, that are not equal to the pillars in the middle of the river and one on the side, were obtained. These data should contribute to clearer image of the layout and structure of the bridge, and according to this map, further research and cages for the remains of the pillars will be created to prevent further detoriation.

2. DETERMINING THE LOCATION OF THE HADRIAN BRIDGE

Due to the complexity, application of multibeam and side-scan sonar is primarily related to open sea and the oceans. Using multibeam and sidescan sonar it is possible to collect a large amount of spatial information about the underwater world in a short period of time. In recent years, however, the range of applications in which multibeam and side scan sonar can be used has greatly broadened.
The aim of the project was to create an accurate bathymetric map of the part of Drava river in the area of the archaeological site. The map would allow archeologists to accurately determine the positions of the pillars of the Hadrian bridge and distances between them. The project was created in collaboration with the Department of Underwater Archeology of the Ministry of Culture.
Strong currents, muddy and sandy soil are the main characteristics of the Drava river, which have a direct impact on the accuracy of the measurements multibeam echosounder. Because of the complexity of the project task, it was necessary to develop a detailed plan of measurements.

2.1 Preparation and conducting of survey

Before the discovery of the statue of Jupiter there was no need for accurate determination of position and direction of the bridge, which was known only to the approximate location. Before creating the planned lines for the survey, it was necessary to determine the position and direction of the bridge. The position of the bridge is essential for determining the areas where the maximum concentration of all operators is required, while the direction of the bridge is essential for the design of cross-line recording.
For this purpose side scan sonar C-Max combined with the RTK GPS Trimble R8 positioning system was used. Based on data obtained in this way, the area of interest was determined with the size of 300x100 meters with an estimated depth from 2 to 8 meters. Based on this survey lines were planned with the recording equidistance of 4 meters. For the purpose of easier maneuvering, smaller boat needed to be used.
For the purpose of data collection multibeam echosounder ES3M Odom with TSS DMS 25 motion sensor and heading sensor 100 Hemisphere was used, and as mentioned above, Trimble R8 RTK was used as a positioning device. The main characteristics of this system are the compactness and functionality that allow it to be installed on a small boat. This is made possible by setting up complete system on a common adapter, which allowed removing the error of determining the offset between the individual sensors. However, it is important to mention limitations of the system that occur due to the accuracy of individual sensors and the instability of the platform (the size of boat). As already mentioned, the main problem for conducting the measurements are strong river currents that make it difficult to maintain the direction of the planned survey lines, especially heading error and roll and pitch error.
Namely, the change in direction and intensity of current results in jerks (drift) which sensors can't detect what then leads to errors in orientation of the measured profile.

Figure 1. Multibeam echosounder and a vessel on which the system was installed

Due to strong currents and sandy composition of soil, water was muddy and full of particles that directly affect the accuracy of the beam and data filtering. Specifically, in the data filtering process it is necessary to distinguish the noise from real data.
Prior to start of measurements with multibeam echosounder it was necessary to calibrate the system with the patch test. The patch test procedure is the first stage required in any multibeam echosounder survey. The patch test is designed to precisely determine the static configuration of the sonar head (roll, pitch, yaw) and the latency remaining between the reception of the GPS fix and its integration by the acquisition system. An imprecise knowledge of these four values introduces bias when computing the real 3D geographic location of each beam. In the proposed patch test program, these four values are sequentially computed, according to tailored track acquisitions. An extended set of measured information is involved, such as the dynamic attitude, position and heading of the supportship, the geometric offsets of each acquisition unit (MRU, GPS, MBES, compass) and some environmental features (sound velocity profile). The computation mainly relies on performing a matching between specific sea-bottom profiles extracted from each overlapping track. (Gueriot et al. 2000).

3. ANALYSIS AND RESULTS

Analysis of measurement data showed that measurements conducted upstream and downstream do not meet the accuracy criteria, and were excluded from further processing. This confirmed the previous assumptions about limitations of the system in stated measurement conditions. Measurements collected in the direction parallel to the axis of the bridge were used for the production of the bathymetric map showing the visible remains of the pillars of the bridge.
Analysis of the data was conducted using HypackMax-Hysweep software. Processed and cleaned data was exported and the bathymetric map was created using Golden Surfer software. The part of the bathymetric map showing remains of the pillars of the Hadrian bridge on river Drava is shown on figure 2, and the longitudinal profile AA' is shown on the figure 3. Span between the pillars can be roughly determined to about 25-30 m which is the distance mentioned in the historic documents.

The map will serve as the basis for further underwater archaeological research in order to protect cultural heritage.

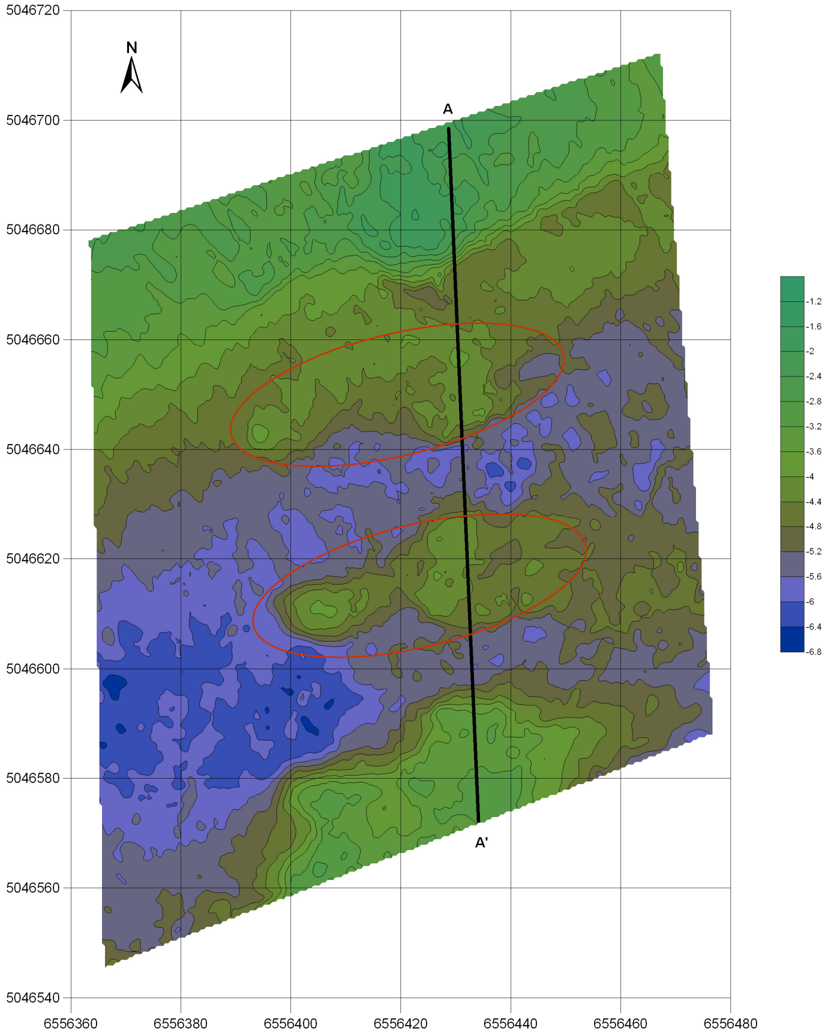

Figure 2. Bathymetric map showing the remains of the pillars of the Hadrian bridge

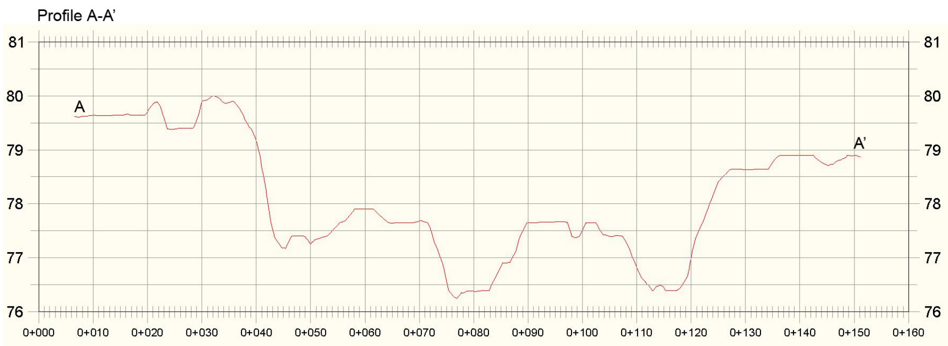

Figure 3. Longitudinal profile AA' of the remains of the Hadrian bridge

4. CONCLUSION

The multibeam echosounder represents very powerfull tool for exploration of underwater archeological sites. It enables an allows collection of high resolution data from which maps and detailed plans can then be compiled.

As described in this paper, this system prove to be the the best solution, first, for the purpose of determining the location of the bridge remains, and second, for documenting the archaeological site and thus creating the first map of the site. Although, due to the advanced technology it requires and the fact that it needs to be mounted on a larger vessel, it is not always accessible or appropriate for use in shallow waters, which is where the majority of underwater Roman structures are positioned.

Here it has to be stated that due to strong currents and sandy composition of soil, water was muddy and full of particles that directly affected the accuracy and level of detail which came out to be less than expected but still satisfactory. Distance between the pillars can be roughly reconstructed from this series of measurements. New series of measurements is planned for the period when the currents will be calmer and river less muddy providing in that way better measurement results. Also, a full scale geophysical research is planned.

River Drava changes its configuration and soon will sand and high water level cover most of Hadrian bridge, and it is of great historical and cultural importance to conduct all interdisciplinary research and find out the truth about the stone bridge which according to legend, was one of the most beautiful roman bridges ever built.

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BIOGRAPHICAL NOTES

Branko Kordić was born on June 07. 1979. in the town of Rijeka in the Republic of Croatia. He has a M.sc. degree in geodesy and geoinformatics, and works as a research assitant at Faculty of Geodesy, University of Zagreb, where is also a Ph.D. student. He has nine years of experience in the field of geodesy and geoinformatics. In that time he worked on large number of projects in different fields of geodesy and geoinformatics.

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