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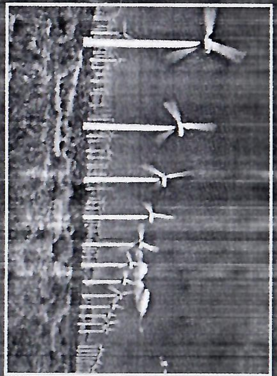
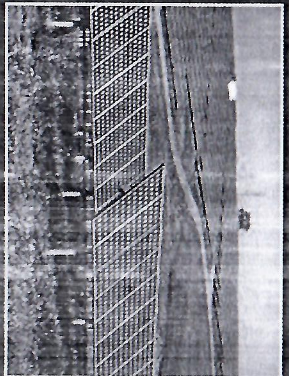
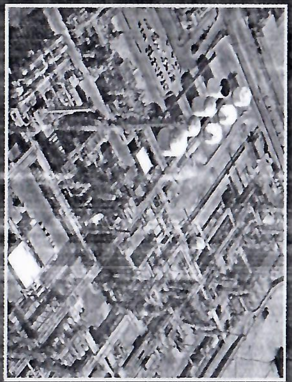
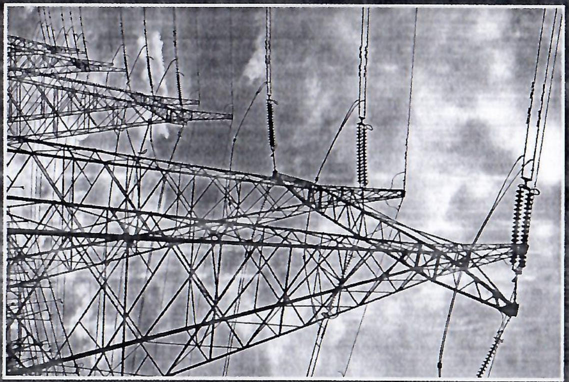


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Integrity of Beam Braces and Threaded Spindle for Conjoint Operation of Two 5 MN Bridge Cranes

ABSTRACT

The beam connects two bridge cranes with the overall lifting capacity of 500 t (2x250 t) and enables their simultaneous conjoint operation during the refurbishment or capital repair of hydroelectric equipment at the hydro power plant "Djerdap 2". Two braces are being installed instead of two hooks when that situation occurs. Braces are loaded with 250 t (2.5 MN) each, while threaded spindle is loaded with 500 t (5 MN).

Integrity of structures is a relatively new scientific and engineering discipline which in a broader sense comprises state analysis, behaviour and loosening diagnostics, service life evaluation and refurbishment of structures, which means that, beside the usual situation in which it is necessary to evaluate the integrity of a structure when a flaw gets detected by means of non-destructive tests, this discipline also comprises structural stress state analysis.

Detection of internal defects by means of ultrasonic testing was performed in order to analyze the state of braces and of the threaded spindle.On the basis of performed analytical calculations it was determined that their integrity would not be jeopardized during the refurbishment or capital repair of hydroelectric equipment at the hydro power plant "Djerdap 2".

Key words: cranes, non-destructive testing, braces, threaded spindle, structural integrity

1. INTRODUCTION

Non-destructive testing performed in order to determine the current state of components of the beam for simultaneous conjoint operation of two bridge cranes with overall lifting capacity of 500 t (5 MN) is only a preparatory action required for their operation during refurbishment or capital repair of equipment at HPP 'Djerdap 2'. On the basis of test results the overall lifting capacity and integrity are being checked. The beam connects two bridge cranes and enables their simultaneous conjoint operation, *figure 1* (marked 1 at *figure 1b*). Threaded spindle (marked 2 at *figure 1b*) is loaded with 500 t, while braces (marked 3 at *figure 1b*), which are being installed instead of hooks during the simultaneous conjoint operation of cranes, are loaded with 250 t each. According to design documentation [1], braces and threaded spindle were made of steel with guaranteed chemical composition OLC 35 (romanian label) by forging. Chemical composition is presented in *table 1*, while mechanical properties are given in *tables 2* and *3*.

Table 1. - *Chemical composition, values in [%]*

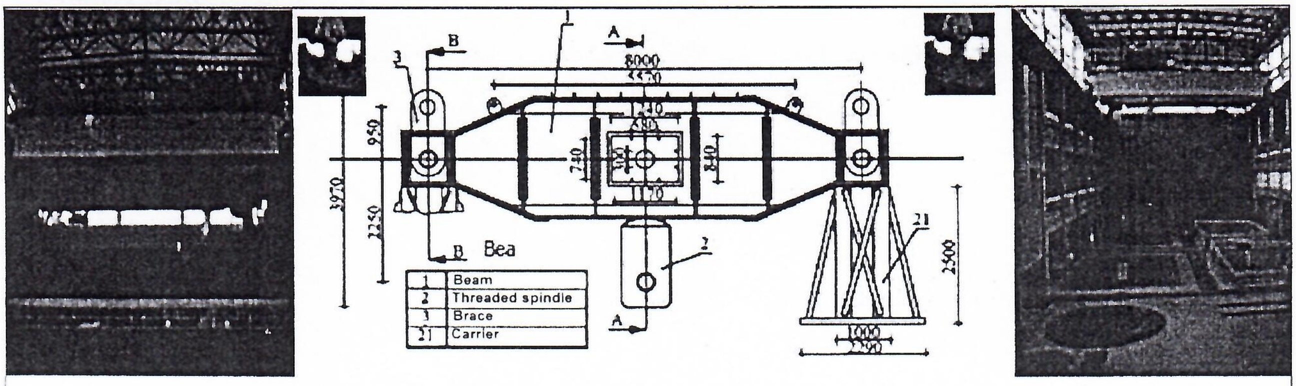
Steel	C	Si	Mn	Cr	Ni	Mo	S	P
OLC 35	0.32-0.39	max 0.4	0.5 - 0.8	max 0.4	max 0.4	max 0.1	max 0.045	max 0.045

Table 2. - *Mechanical properties of steel OLC 35 for the thickness of brace forging t = 220 mm*

Steel	Yield strength, YS [N/mm^2]	Tensile strength, TS [N/mm^2]	Elongation, A5 [%]
OLC 35	245	500	min 15

Table 3. - *Mechanical properties of steel OLC 35 for the thickness of threaded spindle forging t = 900 mm*

Steel	Yield strength, YS [N/mm^2]	Tensile strength, TS [N/mm^2]	Elongation, A5 [%]
OLC 35	210	470	min 15



a) Bridge crane no. 1 b) Beam for the simultaneous operation of bridge cranes c) Bridge crane no. 2

Figure 1. - *Appearance of the beam for simultaneous conjoint operation of two bridge cranes*

2. NON-DESTRUCTIVE TESTING OF BEAM BRACES AND THREADED SPINDLE

In order to perform analysis of the current state, check the lifting capacity and evaluate the integrity of vital beam components (braces, threaded spindle), the following was carried out:

- visual testing (VT) of all components of beam equipment,
- magnetic particle testing (MT) in order to detect surface defects,
- ultrasonic testing (UT) of internal homogeneity,
- metallographic tests by replica method in order to determine the structure of material,
- hardness testing.

2.1 Visual Testing of All Components of Beam Equipment

Visual testing of all components of beam equipment confirmed the existence of products of corrosion, as well as the existence of insignificant mechanical damages. Mechanical damages were repaired by fine grinding, and afterwards all components were submitted to sandblasting and application of anti-corrosive protection.

2.2 Magnetic Particle Testing Performed at Braces and Threaded Spindle

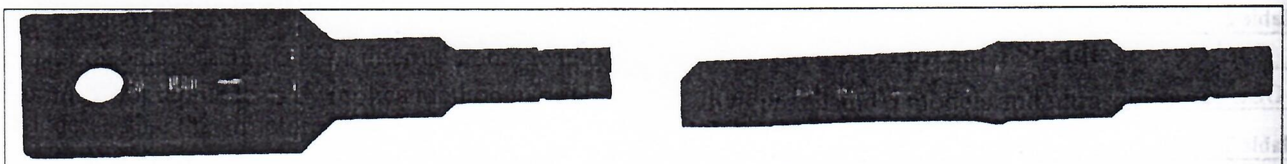
No surface defects were detected during the magnetic particle testing of braces and threaded spindle for the simultaneous conjoint operation of bridge cranes.

2.3 Ultrasonic Testing of Internal Homogeneity of Braces and the Threaded Spindle

In *figures 2* and *3* models and ultrasonic test results for the right brace of the beam (the only one at which internal inhomogeneities were detected) and threaded spindle are shown. Findings, marked with red and yellow colour, refer to areas at which the testing was carried out. On the basis of results of ultrasonic testing, shown in *figures* 2 and *3*, it can be concluded that detected findings are nothing but impurities of lamellar shape grouped around the central area that originated during the forging process, which is a relatively co-

a) View from the upper side of the brace b) View from the lateral side of the brace

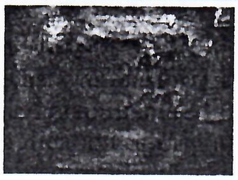
Figure 2. - *Results of ultrasonic testing performed at the right brace*



a) View from the upper side of the threaded spindle b) View from the lateral side of the threaded spindle

Figure 3. - *Results of ultrasonic testing performed at the threaded spindle*

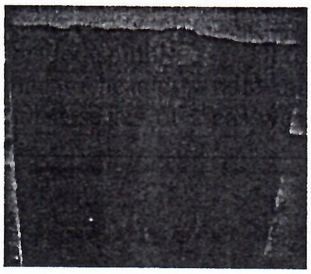
a) Right brace of the beam



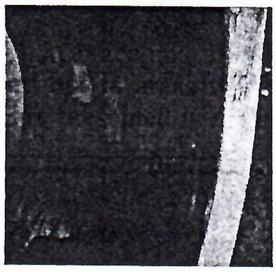
b) Locations at which replicas were taken

Figure 4. - *Locations at which replicas R1A and R2A were taken, right brace of the beam*

a) Threaded spindle



b) Locations at which replicas were taken-TS, external side



c) Locations at which replicas were taken-TS, internal side

Figure 5. - *Locations at which replicas (R1, R2, R3, R4, R5, R1B and R2B) were taken, threaded spindle*

mmon occurrence during the production of large forgings.

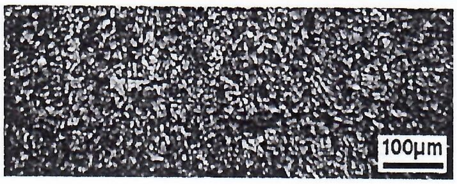
2.4 Metallographic Testing of Right Brace and Threaded Spindle by Means of Replica Method

Metallographic testing of right brace (B) and threaded spindle (TS) material was performed by means of replica method [2]. Locations at which replicas were taken are shown in *figures 4* and *5*.

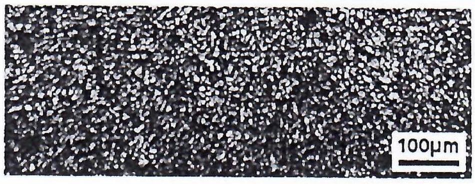
In order to determine the microstructural state of material of the right brace and of the threaded spindle by means of replica method surfaces had to be cleaned, submitted to fine grinding through a series of appropriate operations, polished, rinsed and, finally, etched by means of 4% nital. Metallographic analysis of taken replicas was performed by light microscope 'METAVAL', manufactured by 'Carl Zeiss', Jena, through the application of brightfield technique. A selection of obtained results that refer to the right brace is presented in *figure 6*, while results that refer to the threaded spindle are presented in *figure 7*.

2.5 Hardness Testing

Hardness testing on right brace and threaded spindle material was carried out in areas where replicas were taken. Results are presented in *table 4*. The

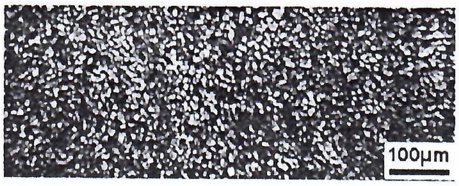


a) Replica R1A

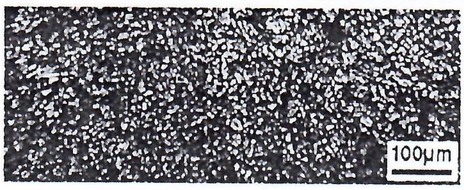


b) Replica R2A

Figure 6. - *Fine-grained ferrite-pearlite microstructure with of corrosion products (B)*



a) Replica R1



b) Replica R2

Figure 7. - *Fine-grained ferrite-pearlite microstructure with of corrosion products (TS)*

Table 3. - *Mechanical properties of steel OLC 35 for the thickness of threaded spindle forging t = 900 mm*

Measurement locations	R1	R2	R3	R4	R5	R1B	R2B	R1A	R2A
Values in HB	135-137	133-135	139-141	140-143	137-141	138-142	138-139	157-164	165-167

overall conclusion is that measured hardness values respond to prescribed values for used materials. The difference in values obtained at the brace with respect to values obtained at the threaded spindle could be explained by smaller thickness of the brace forging.

Table 4. - *Hardness test results in HB*

3. ANALYTICAL CALCULATION OF BRACES AND THREADED SPINDLE

The analytical calculation was performed in order to check the lifting capacity and evaluate the integrity of braces and threaded spindle during the simultaneous operation of two bridge cranes.

3.1 Analytical Calculation of Beam Brace Stress

According to manufacturers' documentation, braces were made of steel OLC 35 [1]. Taking into account the fact that the calculation was carried out for the allowable stress Sall = 120 Mpa, it can be concluded that the safety factor with respect to yield strength (*table 2*) is:

$$S_{BM} = \frac{YS_{0.2}}{S_{all}} = \frac{245}{120} = 2 \quad (1)$$

Dimensions and critical cross-sections used for the analytical calculation of beam braces are shown in *figure 8*.

3.1.1 Calculation of specific stress caused by pressure at the opening of the brace

Specific stress caused by 5 MN pressure at the opening of the brace:

$$S_{PB} = \frac{Q}{2 \cdot d_o \cdot s} = \frac{5000000}{2 \cdot 300 \cdot 220} = 37{,}9 MPa \le S_{all} \quad (2)$$

Safety factor for the calculated stress Sall:

$$S_B = \frac{120}{37{,}9} = 3{,}17 \quad (3)$$

Overall safety factor:

$$S_O = 2{,}0 \text{ x } 3{,}17 = 6{,}34 \quad (4)$$

3.1.2 Calculation of stress at the internal surface of the brace opening,cross-section A1-B1

Stress at the internal surface of the brace opening for 5 MN pressure, cross-section A1-B1:

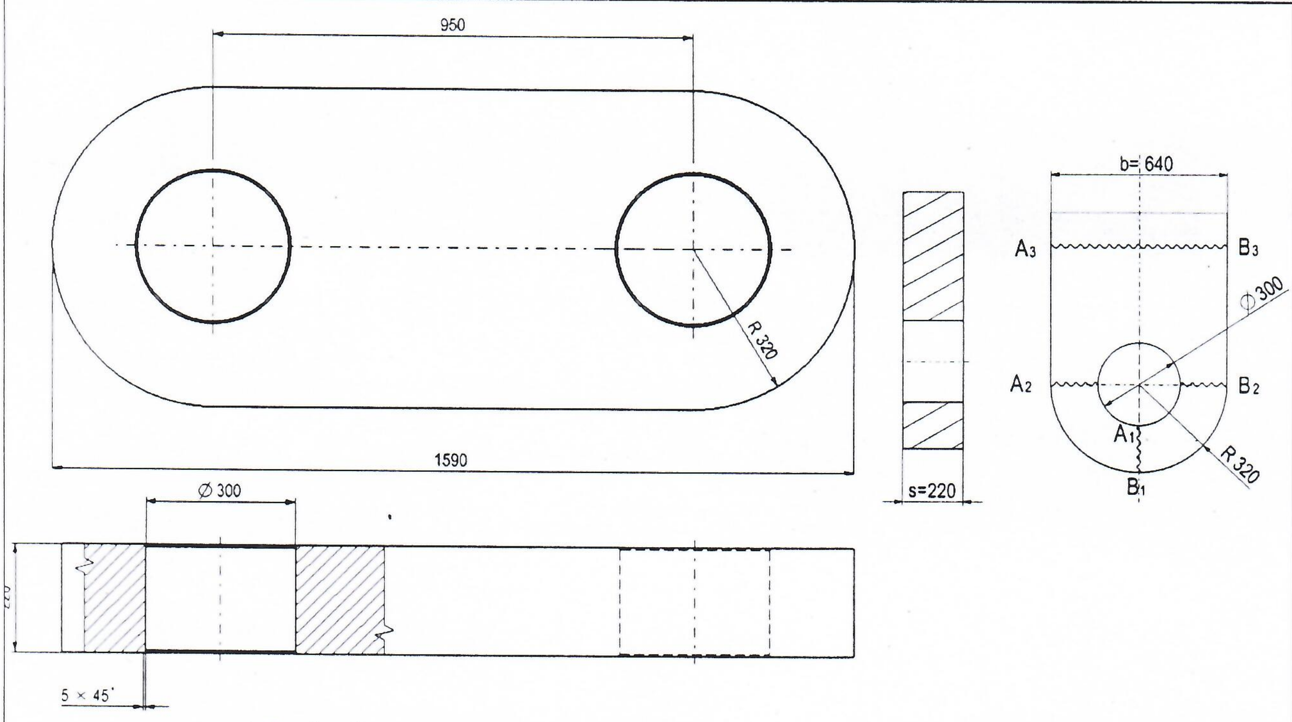
$$S_{A1-B1} = \frac{S_{pBi}\left[(2R)^2 + d^2\right]}{(2R)^2 - d^2} = \frac{37{,}9\left[(2 \cdot 445)^2 + 280^2\right]}{(2 \cdot 445)^2 - 280^2} = 59{,}2 MPa \le Sall \quad (5)$$

Safety factor for the calculated stress:

$$S_{BM} = \frac{120}{59{,}2} = 2{,}03 \quad (6)$$

Overall safety factor:

$$S_O = 2{,}0 \text{ x } 2{,}03 = 4{,}06 \quad (7)$$



a) Basic dimensions of a beam brace b) Critical cross-sections

Figure 8. - *Dimensions and critical cross-sections used for the calculation of beam braces*

3.1.3 Calculation of stress at the internal surface of the brace opening,cross-section A2-B2

Stress at the internal surface of the brace opening for 5 MN pressure, cross-section A2-B2:

$$S_{A2-B2}=\frac{Q}{2\cdot(2R-d)\cdot s}=$$
$$=\frac{5000000}{2\cdot(2\cdot 320-300)\cdot 220}=33,4MPa\le S_{all} \quad (8)$$

Safety factor for the calculated stress:

$$S_{BM}=\frac{120}{33,4}=3,59 \quad (9)$$

Overall safety factor:

$$S_O=2,0\ \mathrm{x}\ 3,59=7,18 \quad (10)$$

3.2 Analytical Calculation of Stress at the Threaded Spindle

Dimensions and critical cross-sections used for the analytical calculation are shown in *figure 9.*

3.2.1 Calculation of stress at the cross-section with diameter 298mm of the threaded spindle

Stress at the cross-section with diameter 298 mm of the threaded spindle loaded with Q_{TS}= 5 MN:

$$S_{TS}=\frac{5000000\cdot 4}{3,14\cdot 298^2}=71,7MPa\le S_{all} \quad (11)$$

Safety factor for the calculated stress:

$$S_{TS}=\frac{120}{71,7}=1,67 \quad (12)$$

Overall safety factor:

$$S_O=1,75\ \mathrm{x}\ 1,67=2,92 \quad (13)$$

3.2.2 Calculation of specific stress caused by pressure at the opening of the eye of the threaded spindle

Specific stress caused by pressure at the opening of the eye of the TS for load Q_{TS} = 5 MN:

$$S_{pTS}=\frac{Q}{d_o\cdot s}=\frac{5000000}{280\cdot 304}=58,7MPa\le S_{all} \quad (14)$$

Safety factor for the calculated stress:

$$S_{TS}=\frac{120}{58,7}=2,04 \quad (15)$$

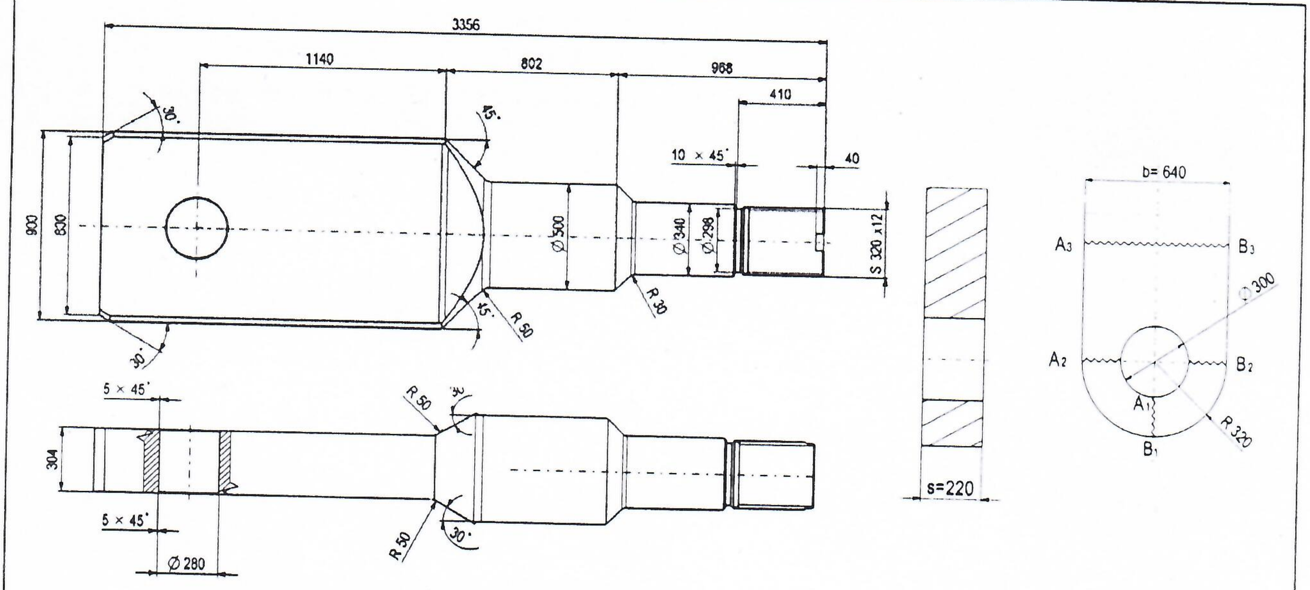
Overall safety factor:

$$S_O=1,75\ \mathrm{x}\ 2,04=3,57 \quad (16)$$

3.2.3 Calculation of stress at the internal surface of the threaded spindle eye opening, cross-section A1-B1

Stress at the internal surface of the eye opening of the threaded spindle for Q_{TS} = 5 MN, cross-section A1-B1:

$$S_{A1-B1}=\frac{S_{pTSi}\left[(2R)^2+d^2\right]}{(2R)^2-d^2}=$$
$$=\frac{58,7\left[(2\cdot 445)^2+280^2\right]}{(2\cdot 445)^2-280^2}=71,6MPa\le S_{all} \quad (17)$$



a) Dimensions of the threaded spindle

b) Critical cross-sections

Figure 9. - *Dimensions and critical cross-sections required for the calculation of the threaded spindle*

Safety factor for the calculated stress:

$$S_{BM} = \frac{120}{33,4} = 3,59 \quad (18)$$

Overall safety factor:

$$S_O = 1,75 \times 1,68 = 2,94 \quad (19)$$

3.2.4 Calculation of stress at the internal surface of the eye opening of the threaded spindle, cross-section A2-B2

Stress at the internal surface of the eye opening of the threaded spindle for Q_{TS} = 5 MN, cross-section A2-B2:

$$S_{A2-B2} = \frac{Q}{(2R-d)\cdot s} =$$

$$= \frac{5000000}{(2\cdot 445-280)\cdot 304} = 27,0MPa \leq S_{all} \quad (20)$$

Safety factor for the calculated stress:

$$S_{TS} = \frac{120}{27} = 4,44 \quad (21)$$

Overall safety factor:

$$S_O = 1,75 \times 4,44 = 7,77 \quad (22)$$

4. CONCLUSION

It can be concluded that non-allowable internal non-homogeneities detected by means of ultrasonic testing of right brace and threaded spindle do not affect the lifting capacity of components required for the simultaneous conjoint operation of two 5 MN bridge cranes, because the analytical stress calculations, presented by appropriate safety factors, showed that practically one third of thickness in characteristic cross-sections of right brace and threaded spindle enable the required integrity of vital beam components during the refurbishment or general repair at HPP 'Djerdap 2'.

ACKNOWLEDGEMENT

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