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ANALYSIS OF CAUSES OF DEGRADATION OF PARENT MATERIAL AND WELD METAL OF BREECHES PIPE AT HYDRO POWER PLANT 'PERUĆICA'

ANALIZA UZROKA DEGRADACIJE OSNOVNOG MATERIJALA I METALA ŠAVA RAČVE NA HIDROELEKTRANI 'PERUĆICA'

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- breeches pipe
- material degradation
- welded joints

Ključne reči
- račva
- degradacija materijala
- zavareni spojevi

Abstract

Presented are results of non-destructive tests performed on the parent material and welded joints of structural parts of a breeches pipe (collar and anchor), and results of destructive tests performed on the parent material of the anchor. Non-destructive testing included visual (VT), magnetic particle (MT), and ultrasonic testing (UT), while destructive tests included determination of chemical composition, tensile properties, impact energy and hardness. Based on test results it is established that the major cause for the occurrence of damage in the carrying structure of the breeches pipe no.1 of pipeline III, or in other words, the degradation of anchor parent material and welded joints between the collar and anchor, and between the pipeline and anchor, is in the fact that the breeches pipe started to lean, not on the collar, as specified by design, but on the anchor that could not endure all loads occurring in service.

Izvod

U ovom radu su prikazani rezultati ispitivanja bez razaranje osnovnog materijala i zavarenih spojeva na nosećim delovima račve (kragna i anker), kao i rezultati ispitivanja sa razaranjem osnovnog materijala ankera. Ispitivanje bez razaranja obuhvatalo je vizuelno ispitivanje (VT), ispitivanje magnetnim česticama (MT) i ultrazvučno ispitivanje (UT), dok je ispitivanje sa razaranjem obuhvatalo određivanje hemijskog sastava, zateznih osobina, udarne energije i tvrdoće. Na osnovu rezultata ispitivanja, utvrđen je osnovni uzrok pojave oštećenja na nosećoj konstrukciji račve br. 1 cevovoda III, odnosno, degradacija osnovnog materijala ankera i zavarenih spojeva između kragne i ankera, i između cevovoda i ankera, uz činjenicu da je račva počela da naleže na anker, umesto na kragnu, kao što je bilo predviđeno, usled čega anker nije mogao da nosi svo opterećenje koje se pojavilo tokom rada.

INTRODUCTION

Hydroelectric power plant 'Perućica', which comprises 7 hydroelectric generating sets with an installed power of 330 MW, is the oldest large hydroelectric power plant in Montenegro. It was put into service in 1960. From the accumulations 'Krupac', 'Slano' and 'Vrtac' the water is being brought to the hydroelectric generating set by three pipelines under pressure of 61 bar, /1/. Pipeline I, 1851 m long with diameters 1.8-2.2 m supplies two hydroelectric generating sets (A1 and A2) with nominal power of 38 MW each. Pipeline II, 1883 m long with diameters 2.1-2.2 m supplies three hydroelectric generating sets (A3, A4 and A5) with nominal power of 38 MW each, while pipeline III, 1931 m long with diameters 2.5-2.65 m supplies two hydroelectric generating sets (A6 and A7) with nominal power of 58.5 MW each, Fig. 2. In Fig. 3 the appearance of the Pelton turbine is shown.

The most problematic area of the HPP 'Perućica' is the structure of pipeline III, in the zone of breeches pipe no.1. The pipeline and the breeches pipe are made of microalloyed steel Nioval 47 (from steel plant 'Jesenice'). Loads in that area, which occur during the process of performing in-service functional tasks (stationary and dynamic loads) and during the disturbed process of exploitation (non-stationary dynamic loads), led to the increase of the level of damaging of the parent material and welded joints at the structural parts of the breeches pipe (collars and anchors), which endangers the integrity of the pipeline structure as a whole, Fig. 4. The role of the collar, over which the breeches pipe leans on the foundation, is to receive static and dynamic loads (mean pressure in the pipeline of 61 bar, specific load caused by the quantity of water in the pipeline, effect of gravitational force) and displacements that occur due to non-stationary dynamic loads, while the anchor has the role in strengthening and balancing the mass of the breeches pipe. Significant propagation of the defect at the carrying structure of breeches pipe no.1, mostly at parent material of the anchor and welded joint, between the collar and the anchor, as well as between the pipeline and the anchor, has led to the fact that in 2012 the breeches pipe started to lean not on the collar, but on the anchor, Fig. 5b.

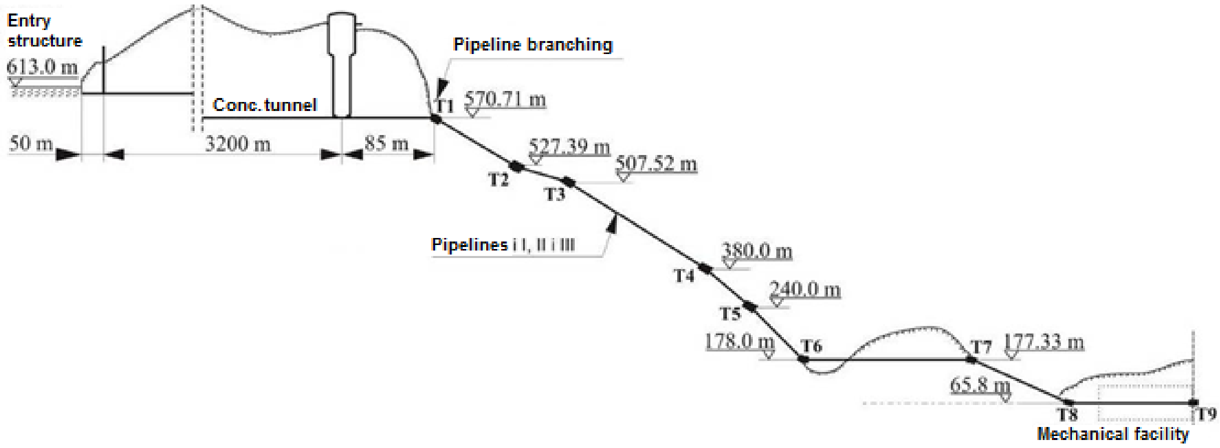
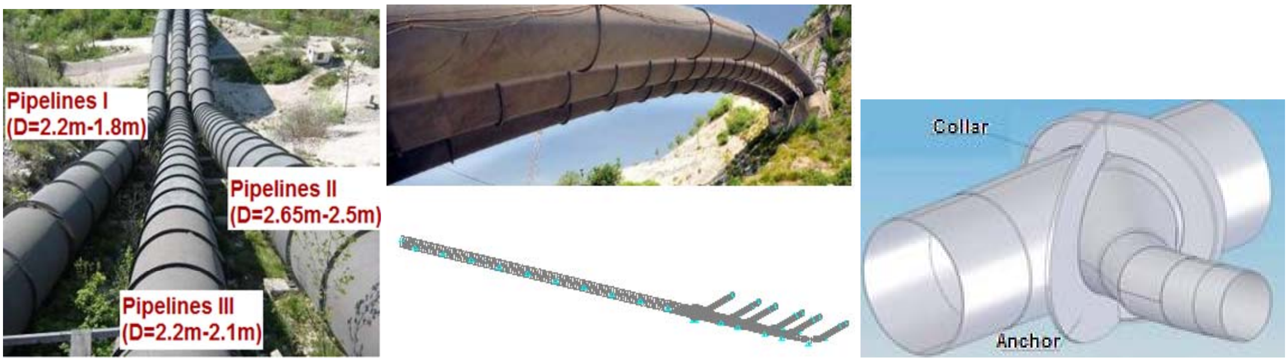
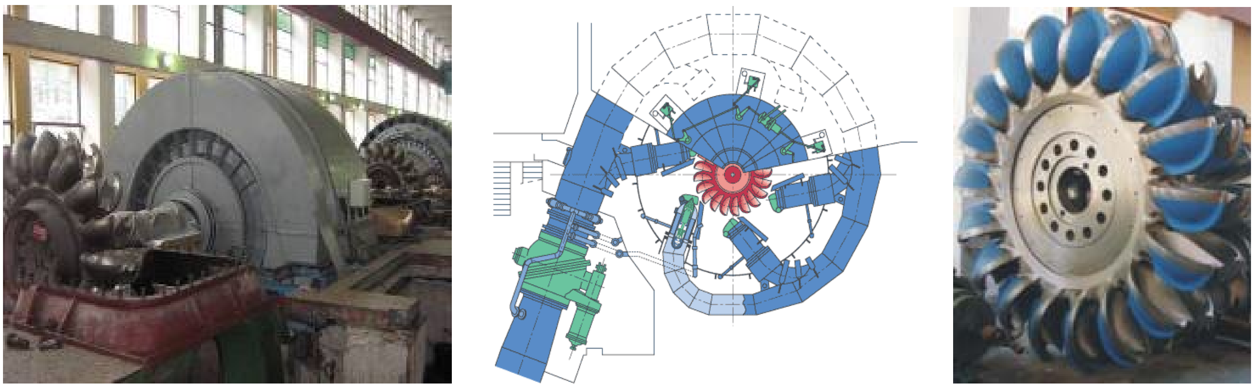


Figure 1. Schematic appearance of hydroelectric power plant ’Perućica’.



a) Pipelines b) Pipeline and model c) Model of the breeches pipe

Figure 2. Intake pipelines with suitable models of pipe and breeches pipe.



a) Hydroelectric generating sets b) Cross-section c) Runner

Figure 3. Appearance of a Pelton turbine.

a) Pipeline branching b) Breeches pipe c) Segment of breeches pipe with defects

Figure 4. Pipeline III with defects in parent material and welded joints.

a) Correct mutual position of collar and anchor b) Incorrect mutual position of collar and anchor

Figure 5. Correct mutual position of collar and anchor at breeches pipe and the damage at the anchor caused by bending initiated by incorrect mutual position of collar and anchor (bending of the anchor is shown in Fig. 5b).

EXPERIMENTAL TESTS

In order to determine the cause of degradation of parent material (PT) and welded joints (WJ) of breeches pipe no.1 at pipeline III, the non-destructive and destructive tests are performed. Non-destructive testing included visual (VT), magnetic particle (MT) and ultrasonic testing (UT), while destructive testing included determination of the chemical composition, tensile properties, impact energy and hardness.

Locations of samples needed for determination of chemical composition, tensile properties, impact energy and hardness are shown in Fig. 6.

Figure 6. Locations of samples for destructive tests.

Tensile and impact energy tests are carried out on specimens from 3 layers and in 3 directions of breeches pipe parent material. Specimens are taken in the direction of sheet metal rolling, perpendicular to the direction of sheet metal rolling, and in the direction of metal sheet thickness.

RESULTS AND DISCUSSION

Non-destructive testing methods

Examples of defects detected at parent material (PT), heat-affected zone (HAZ) and weld metal (WM) of the breeches pipe no.1 through visual (VT), /2/, and magnetic particle testing (MT), /3/, are shown in Figs. 7-9. It is determined through ultrasonic testing (UT), /4/, that cracks in parent material presented in Figs. 7 and 8 are 13-32 mm deep, while cracks in the weld metal are 25-52 mm deep.

Destructive testing methods

Results of quantometric analysis of the chemical composition of the anchor sample of micro-alloyed steel 'Nioval 47' are shown in Table 1 and respond to the chemical composition stated by the steel manufacturer. /1, 5/.

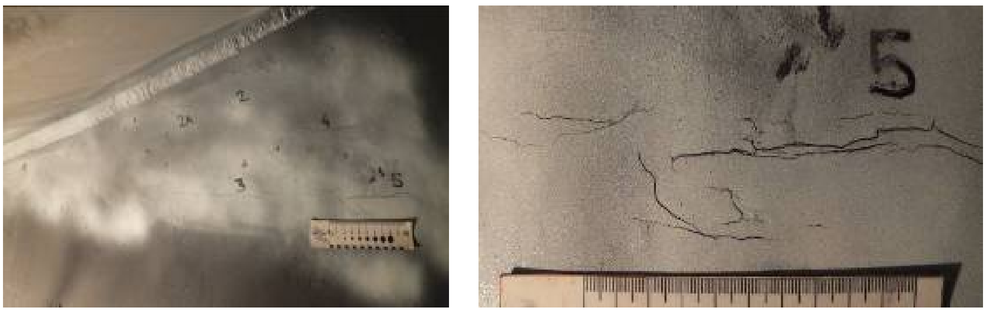
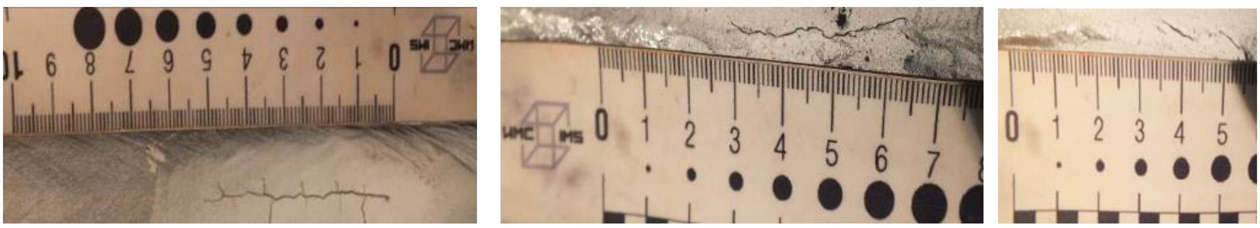


Figure 7. Cracks at the surface of parent material of the anchor of breeches pipe no.1.



a) Cracks at the surface of WM b) Cracks in the HAZ c) Cracks at the surface of PM

Figure 8. Appearance of cracks detected at parent material and welded joints of breeches pipe no.1.

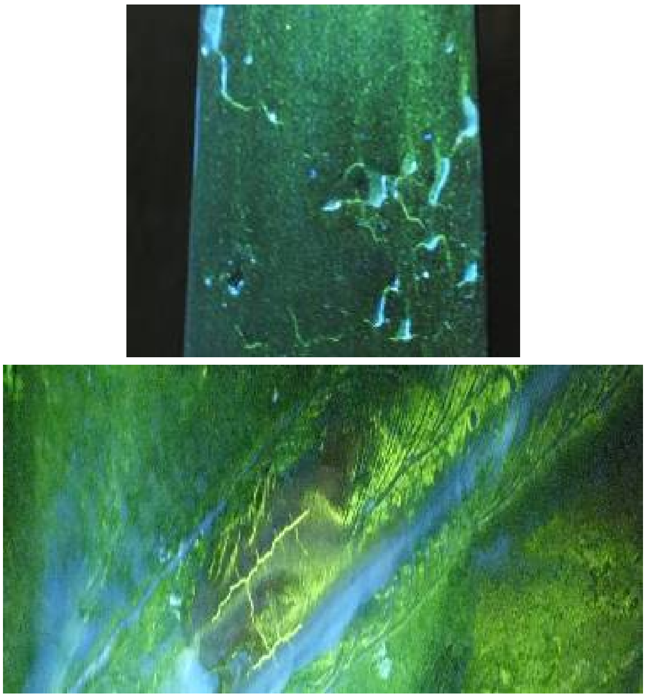


Figure 9. Defects detected in parent material and welded joints of anchor of breeches pipe no.1.

Table 1. Chemical composition results.

Steel	Chemical composition (mass %)						
Nioval 47	C	Si	Mn	P	S	Cr	Ni
	0.17	0.41	1.48	0.012	0.002	0.12	0.09
	Cu	Mo	V	Sn	Nb	Al	
	0.21	0.02	0.07	0.007	0.045	0.061	

From the delivered sample of anchor material 3, standard specimens are extracted in 3 mutually perpendicular directions for tensile testing. Diameter of the measurement area is 8 mm, which is in accordance with the standard /6/. Testing is performed on the machine for tensile, compression, and bend testing, produced by A.J. Amsler, from Switzerland, with a maximal measurement range of 98.1 kN. Test results shown in Table 2 do not deviate from those stated by the manufacturer of microalloyed steel Nioval 47.

Results of standard hardness testing performed on the surface and along the cross-section of polished plates extracted from adequate samples in accordance with the standard, /7/, are presented in Table 3. On the basis of obtained results it can be concluded that they do not deviate significantly from those prescribed by the steel manufacturer.

Table 2. Tensile test results, obtained at 20°C, in accordance with SRPS EN 10002-1.

Sample position	Specimen	Yield strength R_e (N/mm^2)	Tensile strength R_m (N/mm^2)	Elongation $A_{5.65}$ (%)	Contraction Z (%)
Direction of rolling	Surface layer	507	643	30.00	65.48
	Middle layer	516	650	26.50	59.36
	Lower layer	503	643	27.00	60.94
Perpendicular to the direction of rolling	Surface layer	486	630	25.75	66.94
	Middle layer	511	648	27.50	60.94
	Lower layer	487	622	22.50	65.48
z-direction	Surface layer	463	506	6.67	12.89
	Middle layer	469	640	14.00	24.88
	Lower layer	-	147	-	-

Table 3. Results of hardness testing, SRPS ISO 6506-1.

Measurement position	Hardness (HBW 5/750/20°)	Mean value (HB)
On the surface	217, 219, 217	218
Along the cross-section	211, 193, 202	202

Table 4. Impact energy test results, SRPS EN 10045-1.

Sampling position	Specimen	Temperature T (°C)	Impact energy $KV_{2/300}$ (J)	Mean value (J/cm^2]
Direction of rolling	1	+20	120.66	104.97
	2		112.82	
	3		81.42	
Perpendicular to rolling direction	1	+20	139.30	126.55
	2		130.47	
	3		109.87	
z-direction	1	+20	31.39	25.50
	2		21.58	
	3		23.54	

Impact energy tests are performed by Charpy pendulum ‘Alfred Amsler’, with range of 0-300 J, using V2-notch specimens with dimensions of 10×10×55 mm taken from 3 mutually perpendicular directions of the sample, in accordance with the standard /8/. Test results presented in Table 4 are satisfactory.

CONCLUSION

Test results show that the major cause for damage occurrence in the load carrying structure of breeches pipe no.1 of pipeline III at hydroelectric power plant ‘Perućica’, or in other words of the parent material degradation in the anchor and welded joints placed between the collar and the anchor, and between the pipeline and anchor, is that the breeches pipe started to lean not on the collar, as defined by the project, but on the anchor which could not endure all loads that occur during service.

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